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16. ABSTRACT

This report describes a study of air emissions from solvent degreasing and fabric scouring operations. This study was completed to provide EPA with sufficient information to determine whether additional control technology needs to be developed for these emission sources.

Degreasing operations include: 1) cold cleaning; 2) open top vapor degreasing; 3) conveyorized vapor degreasing; and 4) fabric scouring. These four types consumed an estimated 943,000 metric tons of solvent in an estimated 1,255,000 operating locations in 1974.

To assess the potential environmental effect of emissions (hydrocarbons) resulting from degreasing operations, the source severity (defined as the ratio of the time-averaged maximum ground level concentration of a pollutant to a potentially hazardous concentration) was calculated for each solvent emitted from each type of representative degreaser. Methylene chloride (2.2) and perchloroethylene (1.2) from conveyorized vapor degreasing had the two largest source severities. Solvent consumption for degreasing is expected to grow at an annual rate of 4% through 1980. If the 1980 level of emissions control is the same as the 1974 level, emissions from degreasing operations will increase by 26% over that period.

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SOURCE ASSESSMENT:
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This report has been reviewed by the Industrial Environmental Research Laboratory-Cincinnati, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains an assessment of air emissions from solvent evaporation during degreasing operations. This study was conducted to provide EPA with sufficient information to decide whether additional control technology needs to be developed for this emission source. Further information on this subject may be obtained from the Metals and Inorganic Chemicals Branch, Industrial Pollution Control Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Water Act and solid waste legislation. If control technology is unavailable, inadequate, or uneconomical, then financial support is provided for developing needed control techniques for industrial and extractive process industries. Approaches considered include process modifications, feedstock modifications, add-on control devices, and complete process substitution. The scale of the control technology programs ranges from bench- to full-scale demonstration plants.

IERL has the responsibility for developing control technology for a large number of operations (more than 500) in the chemical and related industries. As in any technical program, the first step is to identify the unsolved problems. Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology by IERL. This report contains the data necessary to make that decision for solvent evaporation-degreasing.

Monsanto Research Corporation has contracted with EPA to investigate the environmental impact of various industries which represent sources of pollution in accordance with EPA's responsibility as outlined above. Dr. Robert C. Binning serves as Program Manager in this overall program, entitled "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer for this series.

This study was initiated by IERL-RTP in November 1974, and Mr. Kenneth Baker of the Industrial Processes Division served as EPA Project Leader. Project responsibility was transferred to IERL-Cincinnati in October 1975, and Mr. Charles H. Darvin of the Industrial Pollution Control Division served as EPA Project Leader until the study was completed.

ABSTRACT

This report describes a study of air emissions from solvent degreasing and fabric scouring operations. The study was completed to provide EPA with sufficient information to determine whether additional control technology needs to be developed for these emission sources.

Degreasing operations include: 1) cold cleaning; 2) open top vapor degreasing; 3) conveyorized vapor degreasing; and 4) fabric scouring. These four types consumed an estimated 943,000 metric tons of solvent in an estimated 1,255,000 operating locations in 1974.

To assess the potential environmental effect of emissions (hydrocarbons) resulting from degreasing operations, the source severity (defined as the ratio of the time-averaged maximum ground level concentration of a pollutant to a potentially hazardous concentration) was calculated for each solvent emitted from each type of representative degreaser. Methylene chloride (2.2) and perchloroethylene (1.2) from conveyorized vapor degreasing had the two largest source severities. Solvent consumption for degreasing is expected to grow at an annual rate of 4% through 1980. If the 1980 level of emissions control is the same as the 1974 level, emissions from degreasing operations will increase by 26% over that period.

This report was submitted in partial fulfillment of Contract 68-02-1874 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency.

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ABBREVIATIONS AND SYMBOLS

a -- exponential value of equation

A -- affected area

AAQS -- ambient air quality standard

A_R -- $Q/ac\pi u$ (variable used in ground level concentration derivation)

ASTM -- American Society of Tests and Materials

b -- 0.9031

B_R -- $-H^2/2\ c^2$ (variable used in ground level concentration derivation)

c, c_{1-3} -- coefficient values for equation $\sigma_z = cx^d + f$

C_i -- number of degreasers (each type) of state i

CO -- carbon monoxide

d, d_{1-3} -- coefficient values for equation $\sigma_z = cx^d + f$

D_P -- population density

$\overline{D}_P$ -- mean population density

D_{Pi} -- state population density for state i

e -- constant; 2.72

f, f_{1-3} -- coefficient values for equation $\sigma_z = cx^d + f$

F -- hazard factor. For criteria pollutants, F is the primary ambient air quality standard; for non-criteria pollutants, F is a reduced TLV value; i.e., the equation $F = TLV(8/24)(1/100)$.

h -- emission height

H -- effective emission height

m -- useable range

NEDS -- National Emissions Data System

NO_x -- nitrogen oxides

OSHA -- Occupational Safety and Health Administration

ppm -- parts per million

P' -- total affected population

ABBREVIATIONS AND SYMBOLS (continued)

Q, Q_m -- mass emission rate

S -- source severity

S_{AAQS} -- source severity using a hazard factor based on the AAQS

SIC -- Standard Industrial Classification code

SO_x -- sulfur oxides

S_{TLV} -- source severity using a hazard factor based on the TLV

t -- averaging time

t_o -- short-term averaging time

TLV -- threshold limit value

u -- wind speed

$\bar{u}$ -- average wind speed, 4.5 m/s

x -- downwind distance from emission source

x_1, x_2 -- roots of equation for affected area calculation

y -- horizontal distance from centerline of dispersion

π -- constant; 3.14

σ_y -- standard deviation of horizontal dispersion

σ_z -- standard deviation of vertical dispersion

Σ_i -- summation

χ -- downwind ground level concentration at reference coordinates x and y

$\bar{\chi}(x)$ -- annual mean ground level concentration as a function of distance

χ_{max} -- maximum ground level concentration (short-term average)

$\bar{\chi}_{max}$ -- time-averaged maximum ground level concentration (long-term average)

CONVERSION FACTORS AND METRIC PREFIXES[a]

CONVERSION FACTORS

To convert from	to	Multiply by
Degree Celsius (°C)	Degree Fahrenheit	$t_{^\circ F} = 1.8\ t_{^\circ C} + 32$
Gram/meter^3 (g/m^3)	Pound/gallon	8.344×10^{-6}
Gram/second (g/s)	Pound/hour	7.936
Hertz (Hz)	Cycles/second	1.000
Joules (J)	British thermal unit	9.482×10^{-4}
Joules/second (J/s)	Watt	1.000
Kilogram (kg)	Pound-mass (avoirdupois)	2.205
Meter (m)	Foot	3.281
Meter^2 (m^2)	Inch^2	1.529×10^3
Meter^3 (m^3)	Barrel (42 gallon)	6.293
Meter^3 (m^3)	Foot^3	3.531×10^1
Meter^3 (m^3)	Gallon (U.S. liquid)	2.642×10^2
Meter^3 (m^3)	Liter (ℓ)	1.000×10^3
Meter/second (m/s)	Foot/minute	1.181×10^4
Metric ton	Ton (short, 2,000 pound-mass)	1.102
Pascal (Pa)	Pounds-force/inch^2 (psi)	1.450×10^{-4}
Pascal (Pa)	Torr (mm Hg, 0°C)	7.501×10^{-3}
Second (s)	Minute	1.667×10^{-2}

METRIC PREFIXES

Prefix	Symbol	Multiplication factor	Example
Kilo	k	10^3	1 kPa = 1 x 10^3 pascals
Milli	m	10^{-3}	1 mg = 1 x 10^{-3} meter
Micro	μ	10^{-6}	1 mg = 1 x 10^{-6} gram

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[a] Standard for Metric Practice. ANSI/ASTM Designation: E $380\text{-}76^{\varepsilon}$, IEEE Std 268-1976, American Society for Testing and Materials, Philadelphia, Pennsylvania, February 1976. 37 pp.

SECTION 1

INTRODUCTION

The removal of grease, wax, dirt, and other undesirable matter from various materials ranging from metals to textiles is practiced in industrial operations. These industries range from gasoline service stations to automotive production plants. Emissions from organic solvents used in these degreasing processes can represent a significant source of air pollution.

This document presents a detailed study of degreasing operations from the standpoint of atmospheric emissions and their potential environmental impact. The results of the study, summarized in Section 2, include emission factors for solvents emitted to the atmosphere from representative degreasing operations. Also tabulated are several factors designed to measure the environmental hazard potential of degreasing operations. These consist of source severities, the contribution of degreasing emissions to state and national emissions of criteria pollutants, and the number of persons exposed to high contaminant levels from representative types of degreasing.

Section 3 of this report includes detailed descriptions of the types of degreasing operations. Emission points within each type of degreasing operation and solvents emitted to the atmosphere are presented in Section 4. Present and future aspects of degreasing pollution control technology are provided in Section 5. The growth rate of solvents used in degreasing, as well as degreasing operations, themselves, are analyzed in both Section 3 and Section 6.

Information and data sources used in preparing this report include industry trade literature, government reports, government and contractor emission data files, and personal communications with industry and government representatives.

SECTION 2

SUMMARY

Solvent degreasing is a physical method of removing grease, wax, or dirt from metal, glass and fabric surfaces or fabrics by contacting the material with an organic solvent. Degreasing is one of the production steps or service operations performed in the industries listed in Table 1.

TABLE 1. SOURCE TYPES UTILIZING DEGREASING

Source type	SIC	Number of plants	Degreasing operations
Industrial degreasing:			
Metal furniture	25	9,233	24,361
Primary metals	33	6,792	19,105
Fabricated products	34	29,525	81,469
Nonelectric machinery	35	40,792	110,758
Electric equipment	36	12,270	38,022
Transportation equipment	37	8,802	24,673
Instruments and clocks	38	5,983	18,026
Miscellaneous	39	15,187	40,148
Automotive:			
Auto repair shops and garages	75	127,203	141,977
Automotive dealers	55	121,369	135,463
Gasoline stations	55	226,455	252,753
Maintenance shops	_[a]	320,701	357,945
Textile plants (fabric scouring)	22	7,201	9,451
Total		931,513	1,254,151

[a] No applicable SIC for this category.

When assessing emissions from degreasing and their environmental effects, the type of degreasing operation and the solvent used in it determine the amount of emissions and their environmental impact. The type of plant in which the degreasing operation is performed, however, has no effect. Therefore, emissions from degreasing have been assessed on the basis of the type of degreasing performed and the type of solvent used--not on the location and nature of the plant.

The types of degreasing performed in the United States fall into four categories, which are: 1) cold cleaning; 2) open top vapor degreasing; 3) conveyorized vapor degreasing; and 4) fabric scouring. Cold cleaning operations involve using organic solvents as room temperature liquids. Uses include wiping, spraying or dipping of parts in a solvent for cleaning purposes. In open top vapor degreasing, a part is cleaned by contacting it with solvent vapor. Conveyorized vapor degreasing entails the same activity as open top vapor degreasing, except the parts to be cleaned continuously move in and out of the degreaser. In fabric scouring, a textile fabric is cleaned with a liquid solvent before fabrication into a finished product.

Each type of degreasing requires specific solvents, as listed in Table 2. In 1974, an estimated total of 943,000 metric tons[a] of solvent were consumed in 1,255,000 degreasing operations.

TABLE 2. SOLVENTS USED IN DEGREASING

Solvent	Type of degreasing Cold cleaning	Vapor (open top)	Vapor (conveyorized)	Fabric scouring
Butanol	x			
Acetone	x			
Methyl ethyl ketone	x			
Hexane	x			
Naphtha	x			
Mineral spirits	x			
Toluene	x			
Xylenes	x			x
Cyclohexane	x			
Benzene	x			x
Ethers	x			
Carbon tetrachloride	x			
Fluorocarbons	x	x	x	
Methylene chloride	x	x	x	
Perchloroethylene	x	x	x	x
Trichloroethylene	x	x	x	x
Trichloroethane	x	x	x	

---

[a] 1 metric ton equals 10^6 grams; conversion factors and metric system prefixes are presented in the prefatory material.

Sources of atmospheric emissions (hydrocarbons) from each type of degreasing are: 1) cold cleaning--bath evaporation, solvent carryout, agitation and spray evaporation; 2) open top vapor degreasing--diffusion, solvent carryout, and exhaust; 3) conveyorized vapor degreasing--diffusion, solvent carryout, and exhaust; and 4) fabric scouring--inlet and outlet losses, solvent carryout, and exhaust.

Control technology available for reducing these emissions includes improved covers, higher freeboards, refrigerated chillers, and carbon adsorption for solvent bath evaporation and exhaust; and drainage facilities and drying tunnels for solvent carryout. Reducing emissions by implementing these control measures relies essentially on manual operating performance and maintenance activities. Therefore, percent reduction in emissions based on these control measures cannot be established with any factual certainty.

An emission factor for each of the four types of degreasing was computed using solvent consumption and waste solvent disposal data. These uncontrolled emission factors represent emissions from the particular degreasing operation itself and do not include emissions due to evaporation from waste solvent sludge, wastewater, or solvent reclaiming. The emission factors and solvent consumption data were used to generate a number of other factors designed to quantify the potential environmental hazard from each type of degreasing. A representative degreaser by type of degreasing operation was defined for each type of solvent. The characteristics of each representative degreaser are presented in Table 3. The source severity was defined as the ratio of the time-averaged maximum ground level concentration to a potentially hazardous concentration of a given pollutant from a given source. Using Gaussian plume dispersion theory, source severities were calculated for each type of solvent emitted based on both the threshold limit value (TLV®) of the specific solvent and the ambient air quality standard (AAQS) for hydrocarbons. Results are summarized in Table 4. In addition, the annual mass emissions from all degreasing operations and the percent contribution of these emissions to total mass emissions of hydrocarbons from all stationary sources in the United States were calculated. Results are also presented in Table 4. Mass emissions from degreasing on a state-by-state basis were also calculated and are presented in Tables 29 through 32 in Section 4 of this report.

The average number of persons exposed to high contaminant levels from each type of degreasing operation was estimated and designated as the "affected population". The calculation was made for each solvent emitted from each representative type of degreasing operation for which the source severity exceeds 0.1 and 1.0 for a hazard factor based on both the TLV of each solvent and the AAQS. The largest value obtained was 273 persons due to methylene chloride emissions from conveyorized vapor degreasing (S = 2.2) where the hazard factor is the AAQS and the source severity exceeds 0.1.

TABLE 3. REPRESENTATIVE DEGREASER CHARACTERISTICS

Degreaser type Solvent used	Representative characteristics: Average solvent consumption, kg/yr	Average stack height, m	Frequency of operation, %
Cold cleaning:			
Butanol	53.6	10.6	65
Acetone	126.3	10.6	65
Methyl ethyl ketone	177.6	10.6	65
Hexane	420.6	10.6	65
Naphthas	454.7	10.6	65
Mineral spirits	420.6	10.6	65
Toluene	256.6	10.6	65
Xylenes	420.6	10.6	65
Cyclohexane	420.6	10.6	65
Benzene	420.6	10.6	65
Ethers	3,410.2	10.6	65
Carbon tetrachloride	68.2	10.6	65
Fluorocarbons	89.7	10.6	65
Methylene Chloride	2,187.8	12.1	80
Perchloroethylene	249.2	10.7	78
Trichloroethylene	292.8	12.0	78
Trichloroethane	568.2	14.1	96
Open top vapor degreasing:			
Fluorocarbons	3,806	10.6	65
Methylene chloride	24,518	12.1	80
Perchloroethylene	10,070	10.7	78
Trichloroethylene	7,165	12.0	78
Trichloroethane	16,394	14.1	96
Conveyorized vapor degreasing:			
Fluorocarbons	9,403	10.6	65
Methylene chloride	60,053	12.1	80
Perchloroethylene	24,883	10.7	78
Trichloroethylene	17,780	12.0	78
Trichloroethane	40,468	14.1	96
Fabric scouring:			
Benzene	21,664	10.6	65
Xylene	21,664	10.6	65
Perchloroethylene	21,664	10.7	78
Trichloroethylene	21,664	12.0	78

Solvent consumption for degreasing totaled 942,710 metric tons in 1974. Consumption in 1980 is expected to total 1,192,830 metric tons assuming an annual growth rate of 4%. Thus, assuming that the same level of control exists in 1980 as existed in 1974, emissions from degreasing operations will increase by 26% over that period; i.e.,

$$\frac{\text{Emissions in 1980}}{\text{Emissions in 1974}} = \frac{1{,}192{,}830}{942{,}710} = 1.26$$

TABLE 4. SOURCE SEVERITIES FOR UNCONTROLLED EMISSIONS FROM DEGREASING OPERATIONS AND THEIR CONTRIBUTION TO TOTAL U.S. EMISSIONS

Degreaser type / Material emitted	Emission factor, g/kg solvent consumed	Emissions from all operations, metric tons/yr	Contribution to total U.S. hydrocarbon emissions, %	Source severity (S)		Affected population			
						For S≥0.1		For S≥1.0	
				TLV	AAQS	TLV	AAQS	TLV	AAQS
Cold cleaning:	430 ± 30	203,097	1.2249						
Butanol		1,420	0.0086	0.00018	0.0016	0	0	0	0
Acetone		4,304	0.0260	0.00005	0.0039	0	0	0	0
Methyl ethyl ketone		3,228	0.0195	0.00030	0.0053	0	0	0	0
Hexane		3,012	0.0182	0.00120	0.0130	0	0	0	0
Naphthas		80,917	0.4880	0.00050	0.0140	0	0	0	0
Mineral spirits		12,910	0.0779	0.00076	0.0130	0	0	0	0
Toluene		6,024	0.0363	0.00070	0.0078	0	0	0	0
Xylenes		5,163	0.0310	0.00098	0.0130	0	0	0	0
Cyclohexane		430	0.0026	0.00041	0.0130	0	0	0	0
Benzene		3,012	0.0182	0.01400	0.0130	0	0	0	0
Ethers		2,582	0.0156	0.0029	0.0078	0	0	0	0
Carbon tetrachloride		309	0.0018	0.00100	0.0093	0	0	0	0
Fluorocarbons		2,581	0.0156	0.00001	0.0027	0	0	0	0
Methylene chloride		19,883	0.1199	0.00190	0.0410	0	0	0	0
Perchloroethylene		4,907	0.0296	0.00031	0.0062	0	0	0	0
Trichloroethylene		18,849	0.1137	0.00036	0.0057	0	0	0	0
Trichloroethane		33,566	0.2024	0.00012	0.0066	0	0	0	0
Open top vapor degreasing:	775 ± 30	150,788	0.9095						
Fluorocarbons		6,283	0.0379	0.0009	0.208	0	12	0	0
Methylene chloride		5,662	0.0342	0.039	0.836	0	92	0	0
Perchloroethylene		24,357	0.1469	0.023	0.450	0	35	0	0
Trichloroethylene		63,525	0.3831	0.0160	0.255	0	56	0	0
Trichloroethane		50,961	0.3074	0.0061	0.343	0	22	0	0
Conveyorized vapor degreasing:	850 ± 30	61,286	0.3696						
Fluorocarbons		2,550	0.0154	0.0025	0.564	0	45	0	0
Methylene chloride		2,297	0.0138	0.105	2.246	9	273	0	18
Perchloroethylene		9,877	0.0596	0.061	1.22	0	109	0	4
Trichloroethylene		25,889	0.1561	0.046	0.693	0	74	0	0
Trichloroethane		20,673	0.1247	0.016	0.929	0	143	0	0
Fabric scouring:	500 ± 30	102,357	0.6173						
Benzene		50,033	0.3018	0.856	0.764	128	76	5	0
Xylene		17,499	0.1055	0.059	0.764	0	76	0	0
Perchloroethylene		27,318	0.1648	0.031	0.625	0	62	0	0
Trichloroethylene		7,507	0.0452	0.031	0.497	0	60	0	0
Total (all degreasing types)		517,528	3.1213						

SECTION 3

SOURCE DESCRIPTION

SOURCE DEFINITION

Solvent degreasing is a physical method of removing grease, wax, or dirt from metal, glass, plastic surfaces, or fabrics by contacting the material with an organic solvent. The source defined as "solvent evaporation--degreasing operations" includes plants utilizing industrial degreasing operations in the manufacture of a finished product; metal or part cleaning activities at auto repair shops, garages, auto dealer establishments, gasoline service stations, and plant maintenance shops; and fabric scouring operations at textile fiber plants. Solvents considered include halogenated hydrocarbons, acetone, ethers, naphthas (petroleum distillates, Stoddard solvents), and toluene.

The types of plants utilizing degreasing can be grouped into 13 general industrial source types, which are listed in Table 5 (1-12) together with the estimated number of degreasing operations for each type of industry. The number of degreasing operations per SIC was estimated using percentages calculated from information presented in Reference 12.

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(1) 1972 Census of Manufactures, Volume II, Industry Statistics, Part 1, SIC Major Groups 20-26. Major Group 22, Textile Mill Products. U.S. Department of Commerce, Bureau of the Census, Washington, D.C., August 1976. pp. 22-1 to 22-3.

(2) 1972 Census of Manufactures, Volume II, Industry Statistics, Part 1, SIC Major Groups 20-26, Major Group 25, Furniture and Fixtures. U.S. Department of Commerce, Bureau of the Census, Washington, D.C., August 1976. pp. 25-1 to 25-3.

(3) 1972 Census of Manufactures, Volume II, Industry Statistics, Part 2, SIC Major Groups 27-34. Major Group 33, Primary Metal Industries. U.S. Department of Commerce, Bureau of the Census, Washington, D.C., August 1976. pp. 33-1 to 33-3.

(4) 1972 Census of Manufactures, Volume II, Industry Statistics, Part 2, SIC Major Groups 27-34. Major Group 34, Fabricated Metal Products. U.S. Department of Commerce, Bureau of the Census, Washington, D.C., August 1976. pp. 34-1 to 34-3.

(continued)

Table 6 (13) lists the 11 Standard Industrial Classification (SIC) definitions for these 13 major industrial and service groups that utilize degreasing including textile plants.

The solvents used in degreasing operations are acetone, benzene, butanol, carbon tetrachloride, cyclohexane, ethers, fluorocarbons, hexane, methylene chloride, methyl ethyl ketone, mineral

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(continued)

(5) 1972 Census of Manufactures, Volume II, Industry Statistics, Part 3, SIC Major Groups 35-39. Major Group 35, Machinery, Except Electrical. U.S. Department of Commerce, Bureau of the Census, Washington, D.C., August 1976. pp. 35-1 to 35-3.

(6) 1972 Census of Manufactures, Volume II, Industry Statistics, Part 3, SIC Major Groups 35-39. Major Group 36, Electric and Electronic Equipment. U.S. Department of Commerce, Bureau of the Census, Washington, D.C., August 1976. pp. 36-1 to 36-3.

(7) 1972 Census of Manufactures, Volume II, Industry Statistics, Part 3, SIC Major Groups 35-39. Major Group 37, Transportation Equipment. U.S. Department of Commerce, Bureau of the Census, Washington, D.C., August 1965. pp. 37-1 to 37-3.

(8) 1972 Census of Manufactures, Volume II, Industry Statistics, Part 3, SIC Major Groups 35-39. Major Group 38, Instruments and Related Products. U.S. Department of Commerce, Bureau of the Census, Washington, D.C., August 1976. pp. 38-1 to 38-3.

(9) 1972 Census of Manufactures, Volume II, Industry Statistics, Part 3, SIC Major Groups 35-39. Major Group 39, Miscellaneous Manufacturing Industries. U.S. Department of Commerce, Bureau of the Census, Washington, D.C., August 1976. pp. 39-1 to 39-3.

(10) 1972 Census of Selected Service Industries, Miscellaneous Subjects. U.S. Department of Commerce, Bureau of the Census, Washington, D.C., December 1975. p. 8-8.

(11) 1972 Census of Retail Trade, Miscellaneous Subjects. U.S. Department of Commerce, Bureau of the Census, Washington, D.C., December 1975. p. 3-3.

(12) Heinz, D. R., and H. W. Krimbill. Emissions Survey. In: Study to Support New Source Performance Standards for Solvent Metal Cleaning Operations, Appendix Reports, D. W. Richards and K. S. Surprenant, eds. Contract 68-02-1329, Task 9, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 30, 1976. Appendix A.

(13) Standard Industrial Classification Manual. U.S. Office of Management and Budget, Washington, D.C., 1972. 649 pp.

TABLE 5. SOLVENT DEGREASING SOURCE TYPES (1-12)

Source	SIC	Number of plants	Estimated number of vapor degreasing operations	Estimated number of cold cleaning operations
Industrial degreasing:				
Metal furniture	25	9,233	492	23,869
Primary metals	33	6,792	1,547	17,558
Fabricated products	34	29,525	5,140	76,329
Nonelectric machinery	35	40,792	5,302	105,456
Electric equipment	36	12,270	6,302	31,720
Transportation equipment	37	8,802	1,917	22,756
Instruments and clocks	38	5,983	2,559	15,467
Miscellaneous	39	15,187	886	39,262
Subtotal		128,584	24,145	332,417
Automotive:				
Auto repair shops and garages	75	127,203		141,977
Automotive dealers	55	121,369		135,463
Subtotal		248,572		277,440
Gasoline stations	55	226,455		252,753
Maintenance shops		320,701[a]		357,945
Textile plants (fabric scouring)	22	7,201		9,451
Total		931,513	24,145	1,230,006

Note.—Blanks indicate not applicable.

[a] Total number of manufacturing plants in United States.

spirits, naphthas (petroleum distillates, Stoddard solvents), perchloroethylene, toluene, trichloroethylene, 1,1,1-trichloroethane, and xylenes.

A breakdown of the type of solvent used and the amount consumed for degreasing on a type-of-plant basis has not been accomplished (personal communication with J. L. Shumaker, Chemical and Petroleum Branch, U.S. Environmental Protection Agency, August 9, 1977). An exhaustive industry survey beyond the limits of this study would be necessary. Therefore, assessing degreasing emissions on the basis of the type of plant utilizing degreasing and

TABLE 6. SIC MAJOR GROUPS AND DEFINITIONS FOR SOLVENT USES (13)

SIC major group	Definition
25	Metal furniture--This major group includes establishments engaged in manufacturing household, office, public building, and restaurant furniture; and office and store fixtures. Establishments primarily engaged in the production of millwork are classified in Industry 2341; wood kitchen cabinets in Industry 2434; cut stone and concrete furniture in Major Group 32; laboratory and hospital furniture in Major Group 38; beauty and barber shop furniture in Major Group 39; and woodworking to individual order or in the nature of reconditioning and repair in nonmanufacturing industries.
33	Primary metals--This major group includes establishments engaged in the smelting and refining of ferrous and nonferrous metals from ore, pig, or scrap; in the rolling, drawing, and alloying of ferrous and nonferrous metals; in the manufacture of castings and other basic products of ferrous and nonferrous metals; and in the manufacture of nails, spikes, and insulated wire and cable. This major group also includes the production of coke. Establishments primarily engaged in manufacturing metal forgings or stampings are classified in Group 346.
34	Fabricated products--This major group includes establishments engaged in fabricating ferrous and nonferrous metal products such as metal cans, tinware, hand tools, cutlery, general hardware, nonelectric heating apparatus, fabricated structural metal products, metal forgings, metal stampings, ordinance (except vehicles and guided missiles), and a variety of metal and wire products not elsewhere classified. Certain important segments of the metal fabricating industries are classified in other major groups, such as machinery in Major Groups 35 and 36; transportation equipment, including tanks, in Major Group 37; professional scientific and controlling instruments, watches, and clocks in Major Group 38; and jewelry and silverware are in Major Group 39. Establishments primarily engaged in producing ferrous and nonferrous metals and their alloys are classified in Major Group 33.
35	Nonelectric machinery--This major group includes establishments engaged in manufacturing machinery and equipment other than electrical equipment (Major Group 36) and transportation equipment (Major Group 37). Machines powered by built-in or detachable motors ordinarily are included in this major group, with the exception of electrical household appliances (Major Group 36). Portable tools, both electric and pneumatic powered, are included in this major group, but hand tools are classified in Major Group 34.
36	Electric equipment--This major group includes establishments engaged in manufacturing machinery, apparatus, and supplies for the generation, storage, transmission, transformation, and utilization of electrical energy. The manufacture of household appliances is included in this group, but industrial machinery and equipment powered by built-in or detachable electric motors are classified in Major Group 35. Establishments primarily engaged in manufacturing instruments for indicating, measuring, and recording electrical quantities are classified in Industry 3825.

(continued)

TABLE 6 (continued)

SIC major group	Definition
37	Transportation equipment--This major group includes establishments engaged in manufacturing equipment for transportation of passengers and cargo by land, air, and water. Important products produced by establishments classified in this major group include motor vehicles, aircraft, guided missiles and space vehicles, ships, boats, railroad equipment, and miscellaneous transportation equipment such as motorcycles, bicycles, and snowmobiles. Establishments primarily engaged in manufacturing mobile homes are classified in Industry 2451.
38	Instruments and clocks--This major group includes establishments engaged in manufacturing instruments (including professional and scientific) for measuring, testing, analyzing, and controlling, and their associated sensors and accessories; optical instruments and lenses; surveying and drafting instruments; surgical, medical, and dental instruments, equipment, and supplies; ophthalmic goods; photographic equipment and supplies, and watches and clocks.
39	Miscellaneous--This major group includes establishments primarily engaged in manufacturing products not classified in any other manufacturing major group. Industries in this group fall into the following categories: jewelry, silverware, and plated ware; musical instruments; toys, sporting goods and athletic goods; pens, pencils, and other office and artists' materials; buttons, costume novelties, and miscellaneous notions; brooms and brushes; caskets; and other miscellaneous manufacturing industries.
75	Automotive repair, services, and garages--This major group includes establishments primarily engaged in furnishing automotive repair, rental, leasing, and parking services to the general public. Automotive repair shops operated by establishments engaged in the sale of automobiles are classified in Group 551; those operated by gasoline service stations are classified in Industry 5541.
55	Automotive dealers--This major group includes retail dealers selling new and used automobiles, boats, recreational and utility trailers, and motorcycles; those selling new automobile parts and accessories; and gasoline service stations.
22	Textile plants (fabric scouring)--This major group includes establishments engaged in performing any of the following operations: 1) preparation of fiber and subsequent manufacturing of yarn, thread, braids, twine, and other cordage; 2) manufacturing broad woven fabric, narrow woven fabric, knit fabric, and carpets and rugs from yarn; 3) dyeing and finishing fiber, yarn, fabric, and knit apparel; 4) coating, waterproofing, or otherwise treating fabric; 5) integrated manufacturing of knit apparel and other finished articles from yarn; and 6) manufacturing of felt goods, lace goods, nonwoven fabrics, and miscellaneous textiles. This classification makes no distinction between the two types of organizations which operate in the textile industry: 1) the "integrated" mill which purchases materials, produces textiles and related articles within the establishment, and sells the finished products; and 2) the "contract" or "commission" mill which processes materials owned by others. Converters or other nonmanufacturing establishments which assign materials to contract mills for processing (other than knitting) are classified in nonmanufacturing industries; establishments which assign yarns to outside contractors or commission knitters for the production of knit products are classified in Group 225.

the type of solvent used in the operation is not possible with existing information. However, information relative to the total number of degreasing operations, the types of degreasing employed, and the kind of solvent used in each type of degreasing is available (1, 12, 14). Utilizing this information, a breakdown of the number of operations using each kind of solvent for each type of degreasing can be estimated. This breakdown, given in Table 7, is the basis for the assessment of solvent emissions from degreasing presented in this report. Thus, the assessment of degreasing operations is based on the type of degreasing rather than on the type of industry using degreasing due to the nature of the available data.

TABLE 7. ESTIMATED NUMBER OF OPERATIONS USING SOLVENTS BY TYPE OF DEGREASING (1, 12, 14)[a]

	Number of degreasing operations			
Solvent	Vapor (open top)	Cold cleaning	Vapor (conveyorized)	Fabric scouring
Butanol		61,647		
Acetone		79,261		
Methyl ethyl ketone		42,273		
Hexane		16,656		
Naphtha		413,854		
Mineral spirits		71,382		
Toluene		54,602		
Xylenes		28,552		4,619
Cyclohexane		2,379		
Benzene		16,656		1,617
Ethers		1,761		
Carbon tetrachloride		10,568		
Fluorocarbons	2,130	66,932	319	
Methylene chloride	298	21,136	45	
Perchloroethylene	3,121	45,795	467	2,522
Trichloroethylene	11,440	149,715	1,713	693
Trichloroethane	4,011	137,386	601	
Total[b]	21,000	1,220,555	3,145	9,451

Note.—Blanks indicate no use of specified solvent in that type of degreasing.

[a] 1974 basis.

[b] Total number of degreasers was taken from Reference 14. Number of degreasers using each type of solvent was estimated using percentages calculated from information in Reference 12.

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(14) Control of Volatile Organic Emissions from Organic Solvent Metal Cleaning Operations (draft document). U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1977. pp. 1-10.

PROCESS DESCRIPTION

Degreasers are used to clean all of the common industrial metals, including malleable, ductile, and gray cast iron; carbon and alloy steel; stainless steel; copper; brass; bronze; zinc; aluminum; magnesium; tin; lead; nickel; and titanium (15).

The degreasing process is adaptable to items of a wide range of sizes and shapes, from transistor components to aircraft sections. The process is also used to clean metal strip and wire at speeds up to 45 m/min to 60 m/min (15).

A general flow diagram for degreasers, regardless of type, is shown in Figure 1. The work to be cleaned is conveyed either manually or automatically (stream 1) into the degreaser. After degreasing is completed, the part is manually withdrawn or automatically conveyed to the next step in the manufacturing process or servicing operation (stream 2). Solvent may be heated in the degreaser by either steam, gas, or electricity (stream 3), depending upon fuel availability. Solvent leaves the degreaser either by diffusion into the atmosphere (stream 4) or by entrainment with the work, so-called "dragout" (stream 5). Diffused solvent (stream 4) may be collected by an exhaust hood and vented

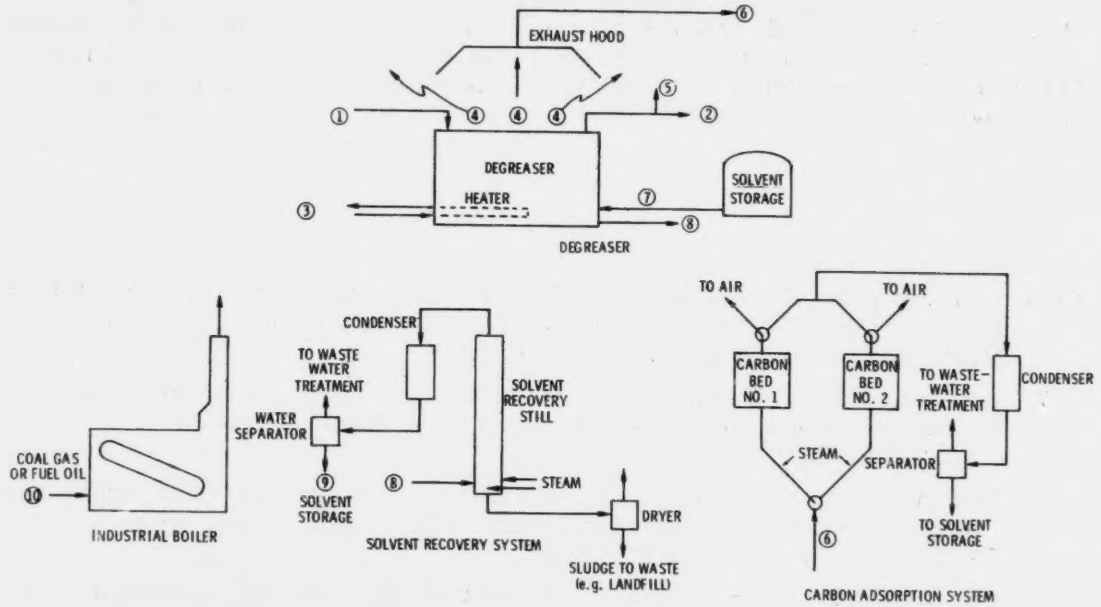
⑥
EXHAUST HOOD
⑤
①
④
④
④
②
DEGREASER
HEATER
⑦
SOLVENT STORAGE
③
⑧
DEGREASER
TO AIR
TO AIR
CARBON BED NO. 1
CARBON BED NO. 2
TO WASTE-WATER TREATMENT
CONDENSER
STEAM
SEPARATOR
⑥
TO SOLVENT STORAGE
CARBON ADSORPTION SYSTEM
CONDENSER
TO WASTE WATER TREATMENT
WATER SEPARATOR
SOLVENT RECOVERY STILL
⑨
SOLVENT STORAGE
⑧
STEAM
DRYER
SLUDGE TO WASTE (e.g. LANDFILL)
SOLVENT RECOVERY SYSTEM
COAL GAS OR FUEL OIL
⑩
INDUSTRIAL BOILER

Figure 1. Degreaser flow diagrams.

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(15) Handbook of Vapor Degreasing. ASTM Special Technical Publication No. 310, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1962. 33 pp.

to either the atmosphere or a carbon adsorption system (stream 6). Solvent loss is balanced by the periodic addition of solvent (stream 7) from storage tanks or drums. Finally, "dirty" solvent, which is solvent contaminated with grease or oil, is removed from the system as necessary and sent to the solvent recovery system (stream 8). The distillate is condensed, sent through a water separator, and finally placed in solvent storage (stream 9). The boiler, which may be fired with coal, gas, or fuel oil (stream 10), provides steam if it is required.

Degreasing operating conditions vary with the application and depend on the item being cleaned. Degreasing is performed at atmospheric pressure and at temperatures ranging from 10°C to 120°C. Mechanical agitation is sometimes used to remove soils.

Open Top Vapor Degreasers

There are seven types of open top vapor degreasers, and they are described individually below (15-20).

Conventional vapor degreaser--

The simplest type of degreaser is the vapor degreaser (Figure 2) (20). The unit is comprised of a sump that holds solvent and a heater that boils solvent to generate solvent vapors. Vapor level is maintained by a water jacket which encircles the machine. The body of the degreaser extends above the water jacket to minimize the escape of solvent vapors. The height of this "free-board" is equal to one-half the tank width or 0.91 m, whichever is shorter (15-17).

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(16) Kearney, T. J. OSHA and EPA as They Apply to Solvent Vapor Degreasing. Detrex Chemical Industries, Inc., Detroit, Michigan, September 1974. 16 pp.

(17) Kearney, T. J., and C. E. Kircher. How to Get the Most from Solvent--Vapor Degreasing, Part I. Metal Progress, 77(4):87-92, 1960.

(18) Kearney, T. J., and C. E. Kircher. How to Get the Most from Solvent--Vapor Degreasing, Part II. Metal Progress, 77(5):93-96, 162, 164, 1960.

(19) Surprenant, K. S., and D. W. Richards. Study to Support New Source Performance Standards for Solvent Metal Cleaning Operations, Final Report. Contract 68-02-1329, Task 9, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 30, 1976.

(20) Today's Concepts of Solvent Degreasing. Detrex Chemical Industries, Inc., Detroit, Michigan. 22 pp.

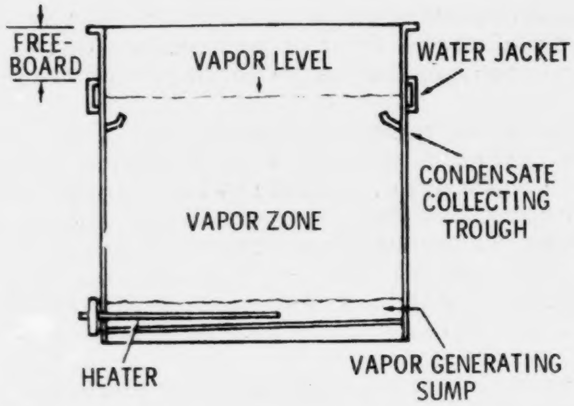
FREE-
BOARD
VAPOR LEVEL
WATER JACKET
CONDENSATE
COLLECTING
TROUGH
VAPOR ZONE
HEATER
VAPOR GENERATING
SUMP

Figure 2. Basic vapor degreaser (20).

Vapor degreasers are satisfactory for removing oils and greases that are partially or completely soluble in the degreasing solvent. Work to be cleaned is immersed in the vapor zone. The solvent condenses on the exposed surface of the part, and the condensed solvent dissolves the grease. This action continues until the part is heated to the vapor temperature. The amount of condensation depends upon the mass of the part and its specific heat. For example, aluminum will condense twice as much solvent vapor as the same weight of steel (15, 17, 21).

Vapor-distillate spray machine--
Vapor-distillate spray machines combine the basic vapor degreaser with a spray system (Figure 3). The work is suspended in the

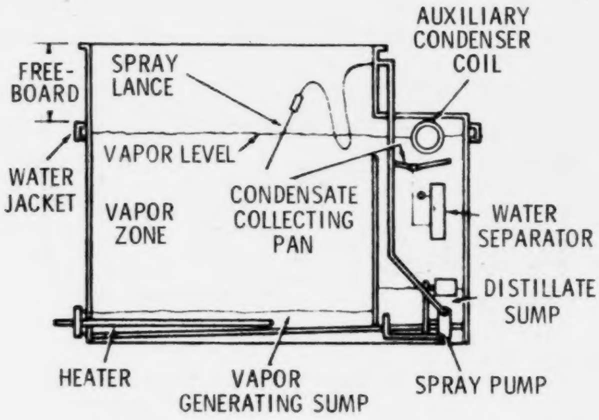
AUXILIARY
CONDENSER
COIL
FREE-
BOARD
SPRAY
LANCE
VAPOR LEVEL
WATER
JACKET
VAPOR
ZONE
CONDENSATE
COLLECTING
PAN
WATER
SEPARATOR
DISTILLATE
SUMP
HEATER
VAPOR
GENERATING SUMP
SPRAY PUMP

Figure 3. Vapor-distillate spray machine (20).

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(21) Payne, H. F. Organic Coating Technology, Volume II. John Wiley & Sons, Inc., New York, New York, 1961. pp. 1019-1020.

vapor zone for degreasing. While still in the vapor zone, parts are flushed with a clean distillate spray which also cools the work surface, thereby promoting further condensation (15, 17, 21).

As shown in Figure 3, condensed solvent is collected in a separate sump to one side of the work zone where it cannot be contaminated by dirt from parts. Distillate flows into the solvent sump and then overflows into the boiling sump. The condensate collection system is equipped with a separator for removing extraneous water. (Water enters the system from the atmosphere and with the work.) All solvent spraying takes place in the vapor zone (15, 17, 21).

Vapor-distillate spraying removes dirt that is partially insoluble in the solvent (e.g., polishing, buffing, and honing compounds). The mechanical action of the spray helps dislodge and remove the insoluble portion. The spray also helps in removing the deposits of soluble materials, assists in cleaning the interior of parts that have cavities containing trapped air, and flushes out passageways (17).

Vapor-spray-vapor degreaser--
The vapor-spray-vapor cycle (Figure 4) is similar to the vapor-distillate-spray cycle. In the vapor-spray-vapor cycle, work is passed through the vapors and into the spray zone before the soluble portion of the dirt is completely removed. The solvent spray then dislodges the heavy soil and cools the parts enough for final vapor cleaning (17).

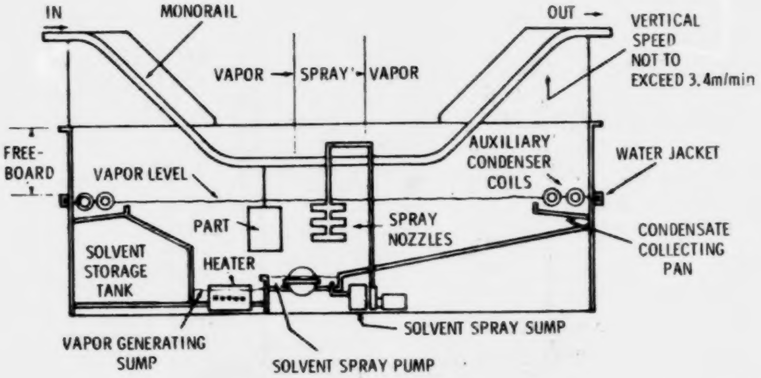
IN
MONORAIL
OUT →
VERTICAL SPEED NOT TO EXCEED 3.4m/min
VAPOR → SPRAY ← VAPOR
FREE-BOARD
VAPOR LEVEL
AUXILIARY CONDENSER COILS
WATER JACKET
PART
SPRAY NOZZLES
SOLVENT STORAGE TANK
HEATER
CONDENSATE COLLECTING PAN
SOLVENT SPRAY SUMP
VAPOR GENERATING SUMP
SOLVENT SPRAY PUMP

Figure 4. Vapor-spray-vapor degreasing unit (20).

Liquid-vapor degreaser--
A liquid-vapor degreaser (Figure 5) consists of two chambers. The first chamber contains boiling solvent which generates vapors. The second chamber is a warm solvent bath in which the parts are immersed. The condensate collection system returns the condensate to the warm solvent bath, thereby constantly

diluting impurities in the bath. Solvent overflows from the immersion chamber into the vapor generating sump (17).

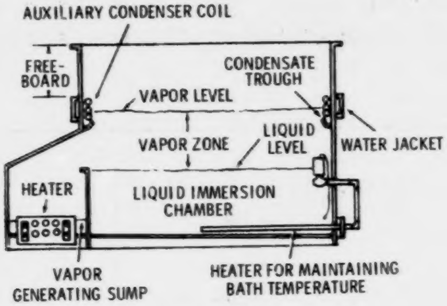
AUXILIARY CONDENSER COIL
FREE-BOARD
CONDENSATE TROUGH
VAPOR LEVEL
LIQUID LEVEL
VAPOR ZONE
WATER JACKET
HEATER
LIQUID IMMERSION CHAMBER
VAPOR GENERATING SUMP
HEATER FOR MAINTAINING BATH TEMPERATURE

Figure 5. Liquid-vapor degreaser (20).

Parts to be cleaned are lowered through the vapors into the immersion chamber where they are washed by the warm solvent. The parts are then withdrawn and held in the vapor to permit complete drainage and to undergo vapor cleaning. The immersion bath temperature is maintained below the boiling point of the solvent so that condensation will occur as the part moves through the vapor zone to allow for vapor cleaning (17). The vertical speed through the vapor zone should not exceed 3.4 m/min to maintain the air-vapor interface. Excessive speed causes solvent loss.

Two-chamber immersion degreaser--
Two-chamber immersion degreasers (Figure 6) are similar to liquid-vapor degreasers in that they consist of a boiling sump and a warm solvent bath. In the two-chamber immersion degreaser, however, cleaning is accomplished by immersing the parts in boiling solvent where the mechanical scrubbing action of the agitated liquid removes insolubles, heavy oils, and greases. From here the part is transferred to a rinse compartment. The part is rinsed with warm solvent which lowers the temperature of the work sufficiently to permit a final vapor cleaning (17).

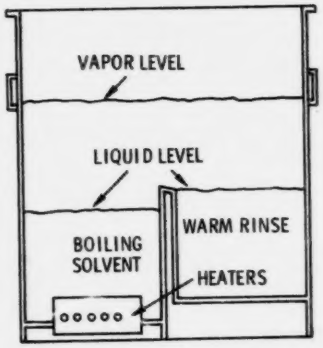
VAPOR LEVEL
LIQUID LEVEL
WARM RINSE
BOILING SOLVENT
HEATERS

Figure 6. Two-chamber immersion degreaser (20).

Multiple immersion degreaser--
The multiple immersion degreaser (Figure 7) is a two-chamber immersion degreaser with a third chamber added. The additional chamber contains solvent vapor that provides a final vapor cleaning. This type of degreaser allows straight line production capability (17).

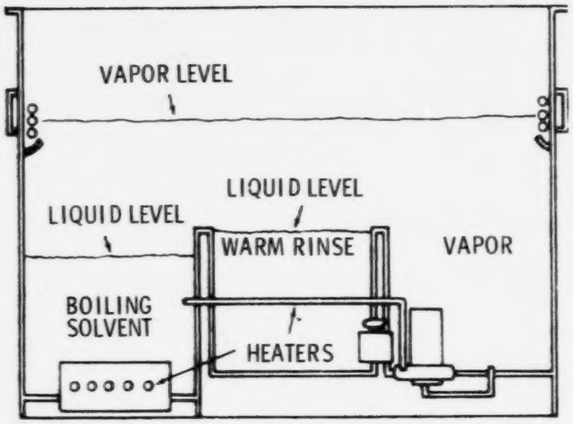

Figure 7. Multiple immersion degreaser (20).

Ultrasonic degreaser--
Ultrasonic degreasing combines a precleaning cycle, such as vapor-spray-vapor or immersion cleaning, with a subsequent treatment by immersion in an ultrasonically agitated liquid bath of the degreasing solvent (Figure 8) (22). Transducers which convert electrical energy to mechanical energy are placed in the bath either at the bottom or on the sides to supply the power for agitation. Solvent filtration for particle size down to 2 µm, 5 µm, or 10 µm, depending on the type of soil, is provided. The frequency and intensity of the ultrasonic energy are selected on the basis of tests. An application example is the removal of residual oil from roller bearing cones. The cones are ultrasonically cleaned in trichloroethylene at 60°C, with the immersed transducers operating at a frequency of 400 kHz (400 kilocycles). The average power intensity at the transducer is 2.5×10^4 W/m^2 (17).

Conveyorized Vapor Degreaser

Conveyorized vapor degreasers employ the same process techniques as do open top degreasers; the only significant difference is material handling. Open top degreasers use hand-held baskets or

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(22) Branson's FD & UD Series Ultrasonic Vapor Degreasers. Branson Cleaning Equipment Co., Stamford, Connecticut, April 1974. 6 pp.

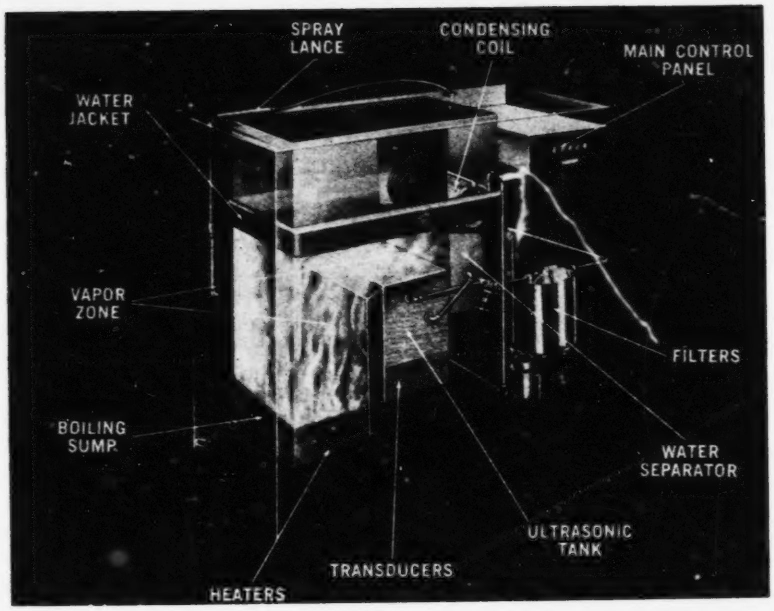
SPRAY LANCE
CONDENSING COIL
MAIN CONTROL PANEL
WATER JACKET
VAPOR ZONE
FILTERS
BOILING SUMP
WATER SEPARATOR
ULTRASONIC TANK
TRANSDUCERS
HEATERS

Figure 8. Ultrasonic degreaser (22).

overhead cranes, powered with either electricity or compressed air motors. In conveyorized equipment, most if not all of the manual parts handling has been eliminated. Conveyorized degreasers are nearly always hooded or covered.

There are seven main types of conveyorized degreasers; each is discussed subsequently.

Cross-rod-degreaser--
The cross-rod degreaser (Figure 9) (23) obtains its name from the rods between the two power-driven chains which convey the parts through the equipment. The parts may be transported in pendant baskets or, where tumbling of the parts is desired, they can be carried in perforated cylinders.

Monorail vapor degreaser--
The monorail vapor degreaser (Figure 10) (23) is chosen when the transportation system between plant manufacturing operations also employs a monorail conveyor. This design lends itself to automatic cleaning with solvent spray and vapor.

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(23) Control of Volatile Organic Emissions from Organic Solvent Metal Cleaning Operations (draft document). U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1977. pp. 2-37, 39-41, 43.

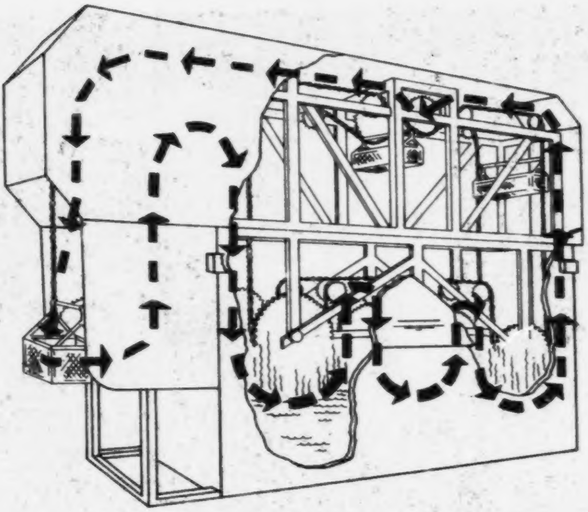

Figure 9. Cross-rod conveyorized degreaser (23).

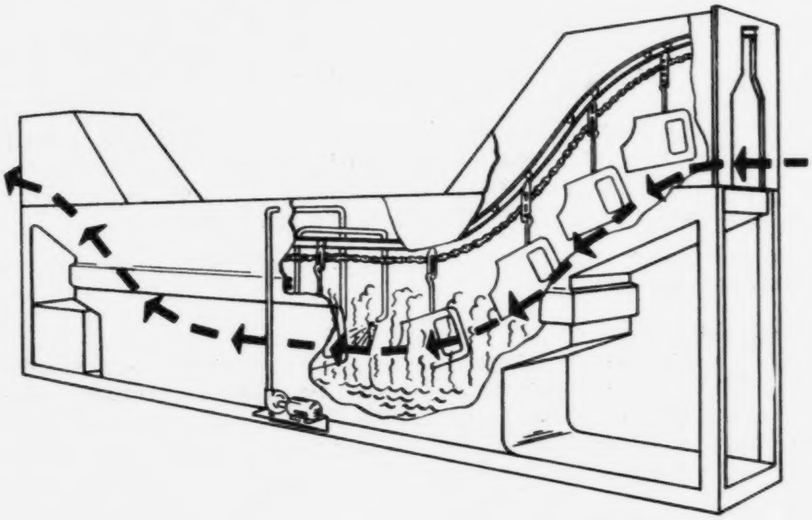

Figure 10. Monorail conveyorized degreaser (23).

Vibra degreaser--

In a vibra degreaser (Figure 11) (23), dirty parts are fed through a chute which directs them into a pan flooded with solvent. The pan is connected immediately to a spiral tray. The pan and spiral tray are vibrated, causing the parts to move from the pan up the spiral tray to the exit chute. The parts condense solvent vapor as they are vibrated up the spiral and dry as soon as they leave the vapor zone.

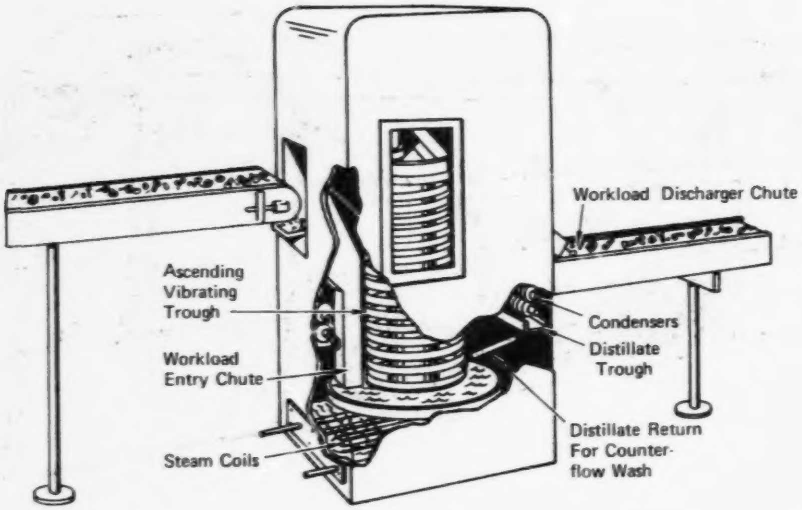
Workload Discharger Chute
Ascending Vibrating Trough
Condensers
Distillate Trough
Workload Entry Chute
Distillate Return For Counter-flow Wash
Steam Coils

Figure 11. Vibra degreaser (23).

Ferris wheel degreaser--
The Ferris wheel degreaser (Figure 12) (23) is one of the cheapest and smallest conveyorized degreasers. It enables use of perforated cylinderical baskets like the cross-rod degreaser can use.

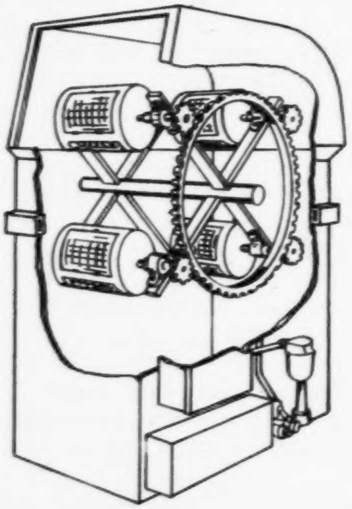

Figure 12. Ferris wheel degreaser (23).

Belt degreaser--
The belt degreaser (Figure 13) (23) enables simple and rapid loading and unloading of parts.

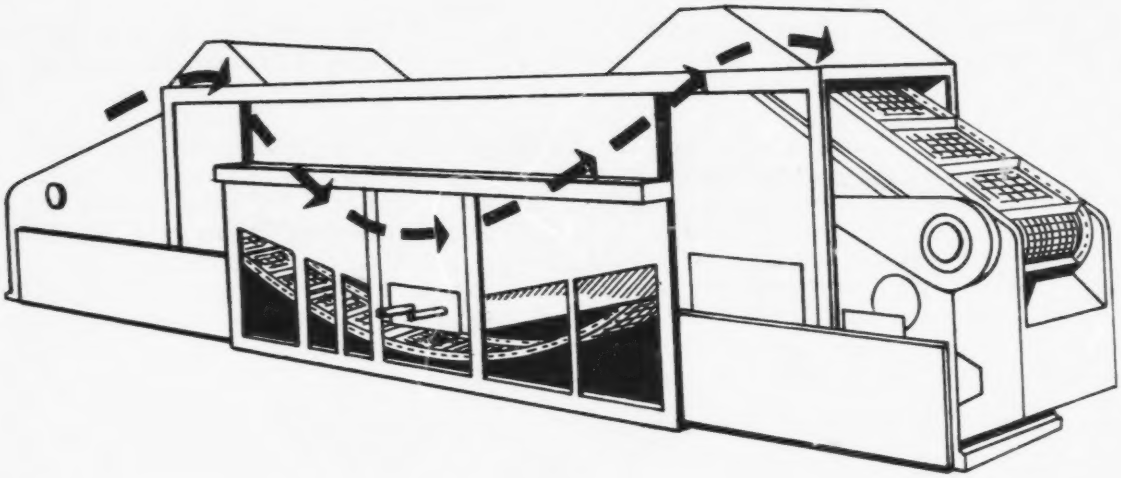

Figure 13. Mesh belt conveyorized degreaser (23).

Strip degreaser--
The strip degreaser is an integral step of fabricating and coating various sheet metal products. The strip in a strip degreaser resembles the belt in a belt degreaser, except the strip itself is the product to be cleaned.

Circuit board cleaners--
The circuit board cleaner type of conveyorized degreaser uses one of the previously described types of degreasers for the specific application of producing printed circuit boards. There are three types of circuit board cleaners: the developer, stripper, and defluxer. The role of these three circuit board cleaners in the manufacturing process is described as follows. Ultraviolet rays are projected through a film of an electrical circuit pattern to create an image on a copper sheet covered with resistance. The developer degreaser dissolves off the unexposed resistance. This copper-covered board is dipped in an acid bath to etch away the copper that is not covered by the hard, developed resistance. Next the stripper degreaser dissolves off the developed resistance. Then a wave of solder passes over the bare copper circuit and bonds to it. Finally the defluxer degreaser dissolves off the flux left after the solder hardens. Because of the nature of the materials being degreased, circuit board cleaners often use cold (room temperature) solvents.

When a solvent is used as a room temperature liquid rather than as a vapor, the process is called cold cleaning. This includes wiping the area to be cleaned, spraying, or dipping in a solvent tank (19). The total number of cold cleaning operations in the United States is estimated to be 1,220,555, excluding fabric scouring (14). It is estimated that 74% of plants using solvents use some form of cold solvent cleaning. The percentage of plants using cold cleaning varies inversely with the size of the plant (19).

Some cold cleaning is done in conveyorized degreasers. Of the seven types of vapor conveyorized degreasers, belt, strip, and circuit board degreasers can also use solvents in the liquid state. Of the estimated 3,700 conveyorized degreasers (14), 550 are room temperature degreasers; e.g., cold conveyorized degreasers. Thus they represent less than 15% of all conveyorized degreasers and less than 0.01% of all cold cleaning operations.

Auxiliary Equipment

In addition to the degreaser unit, auxiliary equipment of the types described below may be associated with each degreasing process.

Solvent Recovery System--

As parts are degreased, the degreasing solvent becomes contaminated. The contaminated solvent is purified when the contaminant level approaches 30%. This level is determined by changes in physical properties such as the solvent boiling point (Tables 8 and 9) (24, 25). The solvent is purified in one of two types of solvent recovery systems (24).

TABLE 8. BOILING POINTS OF CLEAN AND CONTAMINATED SOLVENTS (24)

Solvent	Boiling point, °C Clean	30% Contaminated
Trichloroethylene	87.2	90.5
Perchloroethylene	121.1	126.7
1,1,1-Trichloroethane	74.1	85.0
Methylene chloride	40.0	48.9

One type of recovery system utilizes the degreaser itself as a solvent still. The condensate is collected in a trough and sent first to a water separator and then to reclaimed solvent storage. Contaminants are thus concentrated in the bottom of the degreaser and cleaned out manually. There are two disadvantages to this system. First, production time is lost since the degreaser must be off-line during the cleaning process. Second, as much as 50% of the sludge removed is solvent (15, 24).

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(24) Vapor Degreasers. Branson Equipment Co., Clarke, New Jersey. 11 pp.

(25) Handbook of Chemistry and Physics, 47th Edition, Section C. The Chemical Rubber Co., Cleveland, Ohio, 1966.

TABLE 9. BOILING POINTS OF OTHER COMMON DEGREASING SOLVENTS (25)

Solvent	Boiling point, °C Clean
Carbon tetrachloride	76.8
Acetone	56.5
Butanol	117.2
Ether	35.0
Ethyl isopropyl ether	68.0
Methyl ethyl ketone	80.0
Naphthas (petroleum distillates, Stoddard solvents)	150 to 200
Chlorofluorocarbons	0 to 50
n-Hexane	68.9
Toluene	110.6
Mineral spirits	40 to 80
Xylenes	138.4 to 144.4
Cyclohexane	80.0
Benzene	80.1

The second type of solvent recovery system contains a batch distillation column which may be fed directly from one or more degreasers. Contaminated solvent (stream 8) is distilled with steam, leaving the contaminants as bottoms. Distillate is condensed, sent through a water separator, and finally placed in solvent storage (stream 9). Batch distillation is more efficient than degreaser concentration since the sludge contains approximately 10% solvent. Furthermore, the sludge can be stripped using steam injection to reduce the solvent level to less than 1% (15, 24). It should be noted, however, that due to the formation of acids, steam stripping of some types of solvents, such as 1,1,1-trichloroethane can lead to equipment corrosion, stabilizer depletion, and solvent degradation.

Carbon Adsorption System--
Degreasers can be fitted with carbon adsorption beds to collect and recycle escaping solvent vapors (Figure 1, stream 6). Carbon adsorption systems are discussed in Section 5.

Industrial Boiler--
The steam required by processes with steam-heated degreasers or solvent stills is supplied by an industrial boiler (Figure 1). The boiler may be fired with coal, gas, or fuel oil (stream 10). The environmental impact of industrial boilers is being assessed in other contract studies and will not be discussed further in this report.

Fabric Scouring[a]

Degreasing operations encompass both degreasers, as described above, and fabric scouring. Fabrics are scoured to remove waxes, pectins, dirt, lubricants, warp sizing, and other foreign substances remaining on the fibers or picked up in fabric production. Fabrics are scoured with detergents and water, with organic solvents, by kier boiling, or by enzyme treatment (26). This report discusses only the organic solvent method of fabric scouring.

Types--

Solvent scouring processes fall into three types: textile scouring, wool scouring, and multilayer treatment. All three types clean with liquid solvent and can be classified as types of cold conveyorized degreasers.

Textile scouring process--Figure 14 represents a typical flowsheet for the textile process. Scouring occurs prior to the dyeing step. Figure 15 depicts a fabric scouring machine. Fabric enters the scouring section by conveyor and moves through the scouring section where it is sprayed with solvent. The fabric is supported and tensionless as it is scoured. Still tensionless, it is fed onto the dryer conveyors, traveling from bottom to top. The fabric is then cooled as it leaves the machine. It may be folded, rolled, or fed into the next machine after being scoured (27, 28).

Solvent is collected at two points in the machine. Excess solvent spray is collected beneath the conveyor and sent to a solvent holding tank. Solvent vapors collect at the bottom of the dryer, since this is the coolest point, and are condensed by solvent condensers. Condensed solvent is then sent either to the solvent holding tank or directly to the solvent recovery system (27, 28).

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[a] As used in this report, "scouring" is synonymous with "cleaning." In some literature sources "scouring" means specifically "cleaning with detergent and water."

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(26) Stout, E. E. Introduction to Textiles. John Wiley & Sons, Inc., New York, New York, 1960. pp. 283-284.

(27) Mathews, J. C., et al. Screening Study on the Justification of Developing New Source Performance Standards for Various Textile Processing Operations. Contract 68-02-0607-11, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, August 1974. 106 pp.

(28) Solvent Scouring. Circular No. 721122, Riggs and Lombard, Inc., Springfield, Massachusetts, September 1973. 4 pp.

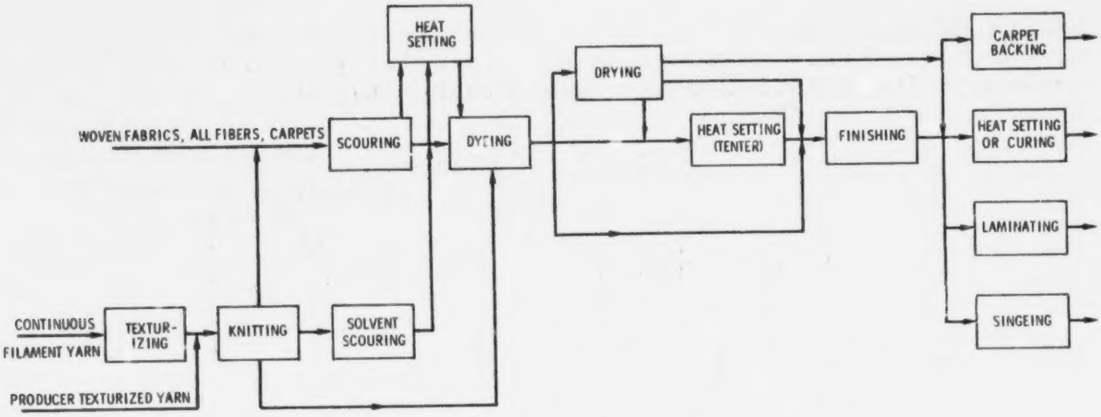
HEAT SETTING
DRYING
CARPET BACKING
WOVEN FABRICS, ALL FIBERS, CARPETS
SCOURING
DYEING
HEAT SETTING (TENTER)
FINISHING
HEAT SETTING OR CURING
LAMINATING
CONTINUOUS FILAMENT YARN
TEXTURIZING
KNITTING
SOLVENT SCOURING
SINGEING
PRODUCER TEXTURIZED YARN

Figure 14. Textile process flowsheet (27).

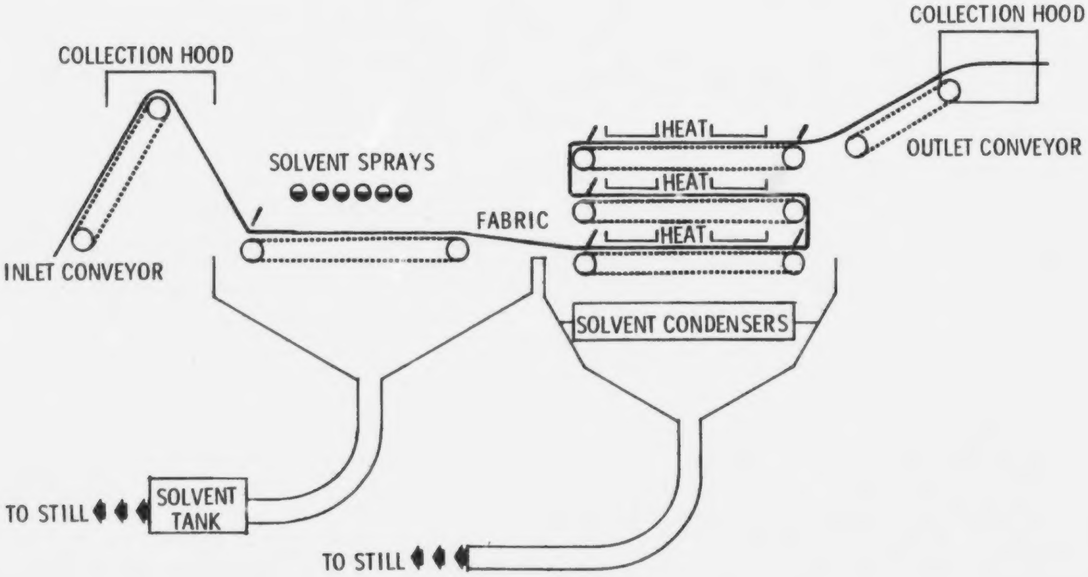
COLLECTION HOOD
COLLECTION HOOD
HEAT
SOLVENT SPRAYS
HEAT
OUTLET CONVEYOR
FABRIC
HEAT
INLET CONVEYOR
SOLVENT CONDENSERS
TO STILL
SOLVENT TANK
TO STILL

Figure 15. Continuous knit fabric scouring (27).

Wool scouring--In this process, wool is scoured with a solvent such as trichloroethylene or perchloroethylene. Solvent is then removed from wool with a mixture of water and alcohol. The cleaning agent containing wool grease is separated from the water and alcohol mixture and recovered in a low pressure, low temperature distillation plant (see Figure 16) (29).

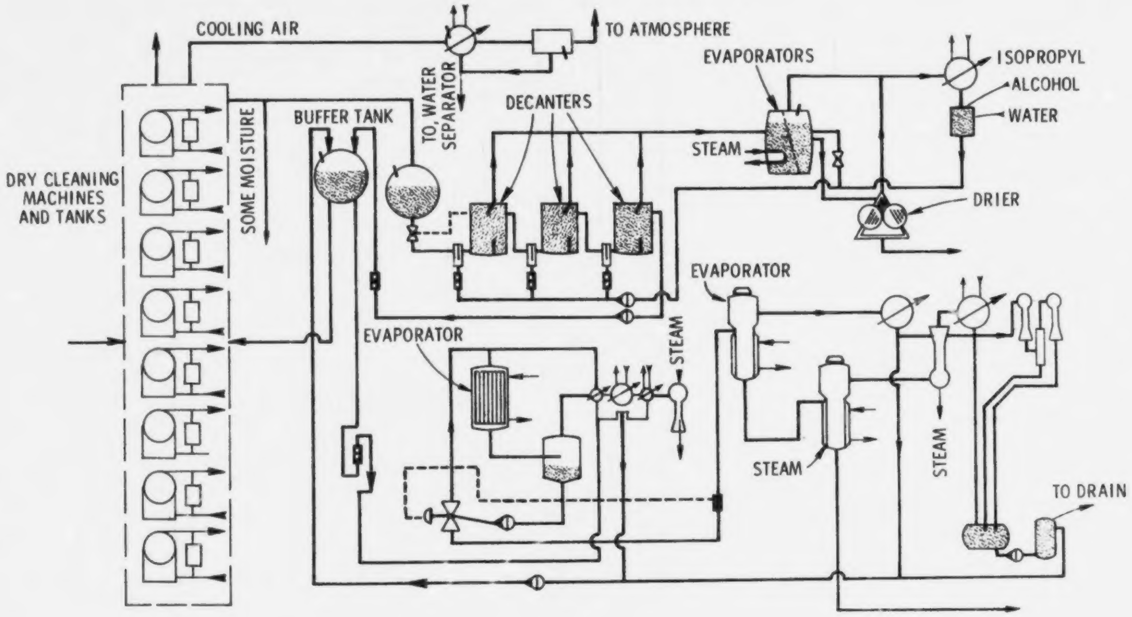
COOLING AIR
TO ATMOSPHERE
EVAPORATORS
ISOPROPYL
ALCOHOL
WATER
TO, WATER SEPARATOR
DECANTERS
BUFFER TANK
SOME MOISTURE
DRY CLEANING MACHINES AND TANKS
STEAM
DRIER
EVAPORATOR
EVAPORATOR
STEAM
STEAM
STEAM
TO DRAIN

Figure 16. Wool scouring process (29).

Multilayer treatment--In this process, textiles are put through solvent scouring in several layers to increase throughput. Organic solvent penetrates these layers, removing both the grease and adhering solvent. Solvents normally used are trichloroethylene, perchloroethylene, 1,1,2-trichloro-1,2,2-trifluoroethane, or mixtures of these. This process is essentially the same as that discussed for textiles except the fabric is put through in multilayer form (30).

Auxiliary Equipment--

Vacuum desolvating process--This process involves passing a textile holding solvent through a vacuum chamber to remove the solvent. The time, vacuum, and temperature can be varied as required. Figure 17 shows the apparatus for this process (31).

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(29) Saville, N. Method of Scouring Wool. U.S. Patent 3,619,116 (to Thomas Burley & Sons, Ltd., London, England), November 9, 1971.

(30) Case, J. W., N. F. Crowder, and W. A. S. White. Treatment of Textiles. U.S. Patent 3,458,273 (to Imperial Chemical Industries, Ltd., London, England), July 29, 1969.

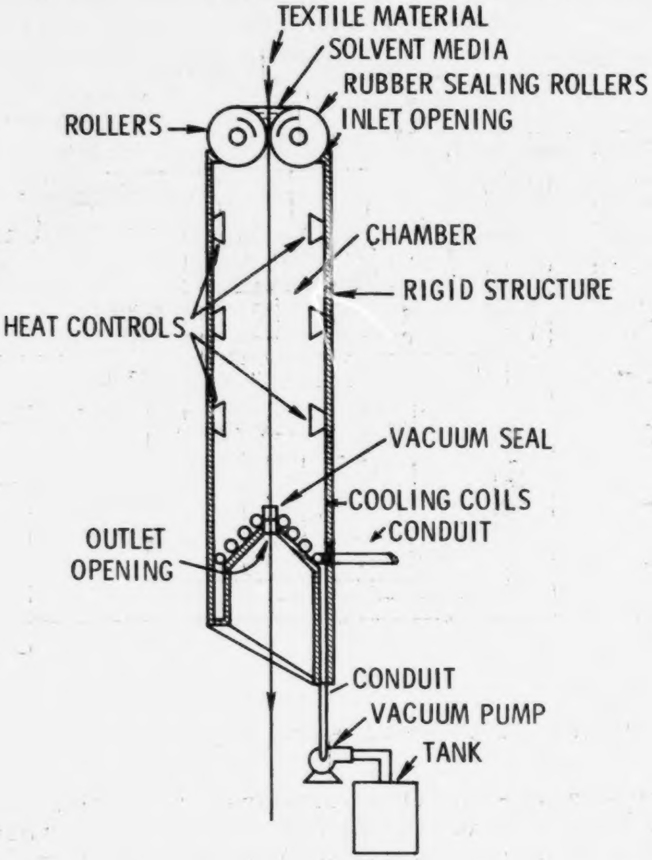
TEXTILE MATERIAL
SOLVENT MEDIA
RUBBER SEALING ROLLERS
ROLLERS
INLET OPENING
CHAMBER
RIGID STRUCTURE
HEAT CONTROLS
VACUUM SEAL
COOLING COILS
CONDUIT
OUTLET OPENING
CONDUIT
VACUUM PUMP
TANK

Figure 17. Vacuum process for the removal of moisture and solvents from textiles (31).

Carbon adsorption system--This system is essentially the same as that to be described in Section 5.

Solvents

Ten characteristics are required of solvents used in degreasing process (15). Solvents must:

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(31) Wedlar, F. C. Process for Removal of Moisture and/or Solvents from Textile Materials. U.S. Patent 3,630,660 (to Burlington Industries), December 28, 1971.

- Either dissolve or attack oils, greases, and other contaminants.
- Have a low latent heat of vaporization and a low specific heat so that a maximum amount of solvent will condense on a given weight of metal and keep heat requirements to a minimum.
- Have a high vapor density relative to air and a low rate of diffusion into the air to minimize solvent losses.
- Be chemically stable under conditions of use.
- Be essentially noncorrosive to common materials of construction.
- Have a boiling point low enough to permit the solvent to be easily separated from oil, grease, and other contaminants by simple distillation.
- Not form azeotropes with liquid contaminants or with other solvents.
- Have a boiling point high enough so that sufficient solvent vapors will be condensed on the work to insure adequate cleaning.
- Be available at reasonable cost.
- Remain nonexplosive under the operating conditions of vapor degreasing.

Table 10 (32-36) lists the physical properties of commercially available solvents. Table 11 (19, 33, 34, 37-41) gives the consumption of the estimated 17 solvents used in degreasing operations. A discussion of each of these solvents follows.

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(32) Lange, N. A., and G. M. Forker. Handbook of Chemistry, Eighth Edition. Handbook Publishers, Inc., 1952. 1998 pp.

(33) Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Volume 7. John Wiley & Sons, Inc., New York, New York, 1965. pp. 307-326.

(34) Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Volume 13. John Wiley & Sons, Inc., New York, New York, 1965. pp. 284-292.

(35) Modern Plastics Encyclopedia, Volume 50, No. 10A. McGraw-Hill Book Co., New York, New York, 1973-74. pp. 744-757.

(36) Heat Exchanger Tube Manual. Scovill Manufacturing Co., Waterbury, Massachusetts, 1957. 171 pp.

(37) Chemical Profile, Trichloroethylene. Chemical Marketing Reporter, 208(12):9, September 22, 1975.

(38) Chemical Profile, Fluorocarbons. Chemical Marketing

(continued)

TABLE 10. PROPERTIES OF COMMERCIALLY AVAILABLE SOLVENTS (32-36)[a]

Solvent	Boiling point (32) °C	Latent heat of vaporization (32), J/g	Specific heat (32), J/g°C	Specific gravity (32) Liquid (water = 1)	Specific gravity (32) Vapor (air = 1)	Evaporation rate (35), (CCl_4 = 100)[b]	Water solubility in solvent (35), (@ 20°C, g/100 g)
Toluene	110.6 (36)	363.4	1.76	0.87	3.14	12	0.05
Methyl ethyl ketone	79.6 (34)	443.8	2.30	0.81	2.41	45	13.4
Acetone	56.7	521.3	2.22	0.79	2.00	91	Complete
Carbon tetrachloride	76.7	218.1	0.84	1.58	5.3[c]	100	0.08
n-Butanol	117.2	591.6	2.34	0.81	2.55	3.5	25.8
sec-Butanol	107.2	576.2	2.34	0.81	2.55	9.4	57.0
Naphtha, coal tar	150 to 200	326 (36)	1.30 (36)	0.90[c]	4.3[c]	1.5 to 12	<0.05
Naphtha, safety (Stoddard)	150 to 200	301.5 (36)	1.34 (36)	0.86[c]	4.3[c]	1.5 to 12	<0.05
Mineral spirits	155 to 175	326.6 (36)	1.34 (36)	0.87[c]	4.1[c]	0.63	<0.05
Ethers (petroleum)	40 to 70	288.9 (36)	1.17 (36)	0.60[c]	2.9[c]	100[b]	<0.05
Benzene	80.1 (33)	394	1.72	0.88	2.77	49	0.05
o-Xylene	143.9 (34)	347	1.72	0.88	3.66	5.5	0.04
Cyclohexane	80.7 (33)	358.4	1.80	0.78	2.90	2[b]	<0.01
Hexane	66.7	337.0	1.55	0.66	2.97	113	<0.01
Trichlorotrifluoroethane	74.1	146.5	0.88	1.514	6.75	280	0.01^24°C
Methylene chloride	40.0	330.4	1.17	1.326	2.93	147	0.15
Perchloroethylene	121.1	209.4	0.88	1.623	5.73	27	0.01
Trichloroethylene	87.2	239.5	0.96	1.464	4.54	69	0.02
1,1,1-Trichloroethane	74.1	221.1	1.09	1.327	4.50	139	0.05^25°C

[a] Specific gravity of vapor phase was calculated using the ideal gas law.

Assuming boiling points for naphtha coal tar, Stoddard, mineral spirits, and ethers of 175°C, 175°C, 165°C, and 55°C, respectively, along with the densities shown, the molecular weights estimated from Reference 21 are 124, 125, 120, and 85, respectively; the density of air is assumed to be 1.293 kg/m³.

Latent heats of vaporization were estimated from Reference 36.

Specific heats were estimated from Reference 36 for the temperature range of 0 to 250°C, where applicable.

API gravities were assumed for the various petroleum fractions, respective to the list above, to be 25°C, 33°C, 31°C, and 100°API.

[b] Carbon tetrachloride is the basis for evaporation rate comparisons. Its evaporation rate is given a value of 100.

[c] Estimated value.

Halogenated Solvents--

Trichloroethylene--Trichloroethylene ($ClCH=CCl_2$) is a stable, colorless liquid emitting a chloroform-like odor (42). It has been used because of its high solvency power and its low cost. From 1961 to 1972, trichloroethylene sold for $0.276/kg (42).

(continued)
Reporter, 208(9):9, September 1, 1975.

(39) Redksted, G. M. Upheaval in Vapor Degreasing. Factory, 7(1):27-32, 1974.

(40) Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Volume 8. John Wiley & Sons, Inc., New York, New York, 1965. pp. 376-377.

(41) Cooper, W. J., et al. Hydrocarbon Pollutant Systems Study, Volume I, Stationary Sources, Effects and Control. Publication No. APTD-1499 (PB 219 073), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, October 1972. 379 pp.

(42) Sax, N. I. Dangerous Properties of Industrial Materials, Fourth Edition. Reinhold Publishing Corp., New York, New York, 1963. 1258 pp.

TABLE 11. DISTRIBUTION OF U.S. SOLVENT CONSUMPTION (19, 33, 34, 37-41)[a,b]

Chemical	1974 Apparent U.S. consumption,[d] 10^3 metric tons	1974 Apparent solvent/degreasing consumption, 10^3 metric tons		1974 Apparent fabric scouring consumption, 10^3 metric tons	Total consumption, wt %[c]						
		Cold	Vapor		Metal cleaning and degreasing	Fabric scouring	Protective coating solvent	Miscellaneous use solvent	Chemical intermediate	Other	Comments
Halogenated hydrocarbons:											
Carbon tetrachloride	534.8	0.72	5		0.13				80	13	6.8 Fumigant
Fluorocarbons	428.6	6	11.1		4				10	50 Aerosol	28 Refrigerant 8 Blowing agents
Methylene chloride	235.4	46.2	10		24			43 Paint remover	12	21	17.7 Aerosol
Perchloroethylene	330.2	11.4	43	54.6	16	16		53 Drycleaning	12	3	
Trichloroethylene	173.7	43.8	112.7	15	90	9		1			
1,1,1 Trichloroethane	236.3	78	90		71			6	23		
Hydrocarbons:											
Hexane	135	7			5		10	15	20	50	
Benzene	5,307	7		35	0.1	0.7			94.2	5	
Toluene	3,085	14			0.5		13	2	19.7	58.3 Fuel	6.8 Nonfuel uses
Xylene	2,635	12		100	0.5	3.8	9	2		70 Isomer	10 Fuel
Cyclohexane	1,066.7	1			0.1					4 Anesthetic	
Ethers	56.3	6			11			60	25	86	
Mineral spirits	210	30			14					40	
Naphthas	4,450	188			4.2		42	12	2		
Ketones:											
Acetone	882.5	10			1.1		10	10	64	15	
Methyl ethyl ketone	237.2	7.5			3.1		72	8	8	8.9	
Methyl isobutyl ketone	70.2						100				
Cyclohexanone	290										
Alcohols:											
Methanol	3,233							8	76	16	
Ethanol	1,105						16	7	48	2	27 Toiletries and disinfectants
Isopropanol	802.9						6		55	39	
Butyl alcohol	159.6	3.3			2.1			22	54.9	21	
Amyl alcohol	20.4										
Esters:											
Amyl, butyl, ethyl acetates	137						60			40	
Glycol ethers:											
Ethylene glycol monomethyl	39.1						12	13	12	63	
Ethylene glycol monoethyl	86.3						33	9	49	9	
Ethylene glycol monobutyl	62.5						41	32	17	17	
Diethylene glycol	30.3						36			64	
Triethylene glycol	35.5										

Note - Blanks indicate not applicable.

[a] Personal communication, J. S. Gunin, Shell Chemical Co., Houston, Texas, October 1976.

[b] Personal communication, K. S. Surprenant, Dow Chemical Co., Midland, Michigan, October 1976.

[c] MRC estimates.

[d] 1 metric ton = 10^6 grams; conversion factors and metric system prefixes are presented in the prefactory pages.

Trichloroethylene can be vaporized using gas, electric, or steam heaters (15). Trichloroethylene can be vaporized with low-pressure (135.7 kPa to 204.6 kPa) steam because of its low boiling point (87.2°C) (15). Stabilized trichloroethylene is used for degreasing applications. In 1976, trichloroethylene at $0.435/kg was the most expensive fabric scouring solvent (43).

Fluorocarbons--In addition to trichlorotrifluoroethane, trichlorofluoromethane and tetrachlorodifluoroethane are also used in solvent cleaning processes on a small, specialized scale. All three have high density (1.5 times that of water), low boiling point (0°C to 50°C), low viscosity, low surface tension, and acceptable stability. Fluorocarbons are principally used as aerosols. Trichlorotrifluoroethane is also used as a solvent in drycleaning operations.

Methylene chloride--Methylene chloride (CH_2Cl_2) is a colorless, volatile liquid (42). It is a low-volume degreasing solvent with an estimated annual consumption of 5.6 x 10^4 metric tons. Methylene chloride is the most active of the degreasing solvents (high solvency power) (44). It also has the lowest boiling point (40.0°C) and the highest latent heat of vaporization (330.2 J/g) of these solvents (45). Since methylene chloride attacks some plastics and elastomers, it cannot be used as a degreasing solvent for these materials (43). The low boiling point requires refrigerated water (12.7°C to 15.5°C) on the degreaser condensing coils, and the high latent heat of vaporization requires removal of more heat than other solvents (16, 44). Methylene chloride is stable under degreasing conditions. In 1976, the cost was estimated to be $0.435/kg (43). Methylene chloride consumption in metal vapor degreasing has more than doubled since 1972, indicating a switch from other solvents such as trichloroethylene.

1,1,1-Trichloroethane--1,1,1-Trichloroethane (methyl chloroform, CH_3CCl_3) is a colorless liquid. It is the largest volume vapor degreasing solvent, with 1.68 x 10^5 metric tons/yr being consumed. 1,1,1-Trichloroethane is the degreasing solvent most like trichloroethylene in its degreasing properties. It has a boiling point of 74.1°C and a kauributanol value of 124 compared to corresponding properties in trichloroethylene of 87.2°C and 129. 1,1,1-Trichloroethane also has a low toxicity rating

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(43) Chemical Marketing Reporter. 209(12):46-56, September 20, 1976.

(44) The United States Environmental Protection Agency and How Its Regulations Will Affect Vapor Degreasing. Baron-Blakeslee, Chicago, Illinois, 1971. 19 pp.

(45) Chemical Engineers' Handbook, Fourth Edition. Perry J. H., ed. McGraw-Hill Book Co., New York, New York, 1963. pp. 3-23 to 3-42.

(TLV = 1.9 g/m^3) (46). This solvent can be heated with gas, electricity, or steam (135.7 kPa to 204.6 kPa) (19, 44). It must be stabilized for degreasing applications because it decomposes in the presence of water to form hydrochloric and acetic acids (19, 44). Improperly stabilized, 1,1,1-trichloroethane can also decompose in the presence of aluminum or magnesium (19, 44). Stabilizers for 1,1,1-trichloroethane (0.05 g/100 g @ 25°C) require a special separator and desiccant to remove water from the system (44). The estimated 1976 cost was $0.467/kg (43).

Perchloroethylene--Perchloroethylene ($Cl_2C=CCl_2$) is a colorless liquid discharging a chloroform-like odor (42). It is the third largest volume vapor degreasing solvent, with 1.1 x 10^5 metric tons consumed each year. The high boiling point (121.1°C) of perchloroethylene is beneficial for two reasons: 1) it aids in the removal of high melting waxes and greases and 2) it allows the solvent to condense on the work for a longer period of time, thereby giving a longer cleaning cycle. Perchloroethylene degreasers may be heated by using gas, steam, or electricity. If steam is used, high pressures (344.7 kPa to 413.6 kPa) are required to attain the boiling point (44). The high temperature can damage certain materials, such as plastics (44). Perchloroethylene is also stabilized for degreasing use. In 1976, the cost was estimated to be $0.377/kg (43).

Carbon tetrachloride--Carbon tetrachloride (CCl_4) is a heavy, colorless liquid with an ethereal odor. It is used occasionally as a solvent and diluent, dry cleaning agent, or degreaser. It is miscible in all proportions with alcohol, benzene, chloroform, ether, and petroleum ether. Carbon tetrachloride has a boiling point of 76.8°C at a vapor pressure of 1.10 KPa. If ingested or inhaled, it will cause injury depending on the dose. Death can result from prolonged exposure to high concentrations. Carbon tetrachloride is not as strong a narcotic as chloroform (42). The cost in 1976 was estimated to be $0.372/kg (43).

Nonhalogenated Solvents--

Acetone--Acetone (CH_3COCH_3) is a colorless liquid giving off a fragrant, mintlike odor. Its molecular weight is 58.08 and its boiling point is 56.48°C. Acetone generally is rated moderately toxic since it may produce reversible or irreversible changes in the human body but not to the extent of threatening life or producing serious permanent physical impairment. In industry, no injurious effects from its use have been reported other than the occurrence of skin irritations resulting from its defatting action (42). It is widely used in industry as a solvent for fats, oils, waxes, nitrocellulose, and other cellulose derivations. The cost in 1976 was estimated to be $0.110/kg (43).

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(46) TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1976. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1976. 94 pp.

Butanol--Butyl alcohol ($CH_3CH_2CH_2CH_2OH$) is a colorless liquid emitting a choking odor resembling that of isoamyl alcohol. It boils in the range of 115°C to 118°C. It is used as a solvent in the manufacture and preparation of various materials such as airplane dopes, lacquers, and plastics. In industry, it is used primarily because of its ability as an extender (making substances soluble in each other) (47). For example, a mixture of acetone, butyl alcohol, methyl or ethyl alcohol, and methyl ethyl ketone in methylene chloride is used as a paint stripper. The 1976 cost of butanol was estimated to be $0.485/kg (43).

Ethers--Ethers are organic compounds in which an oxygen atom is interposed between two carbon atoms in the structure of the molecule (42). The simpler ethers such as ethyl ether and isopropyl ether are powerful narcotics which in larger doses can cause death (42). Most ethers have low flash points, therefore, great care must be exercised when handling them. The lower oxygen-containing ethers are notorious peroxide formers. These peroxides are explosive when concentrated. Also included under the term "ethers" are low-boiling petroleum fractions with properties similar to "true" ethers. Isopropyl ether in 1976 was estimated to cost $0.310/kg, and diethyl ether was estimated to cost $0.175/kg (42).

Methyl ethyl ketone (2-butanone)--Methyl ethyl ketone, $CH_3COCH_2CH_3$, is a colorless liquid discharging an odor resembling acetone. It has a boiling point of 79.57°C and a flash point of -5.5°C. Methyl ethyl ketone has a slight to moderate toxicity rating. Maximum allowable concentration is 250 ppm in air or 735 mg/m^3 (45). The estimated 1976 cost was $0.440/kg (45). It is used as a solvent in numerous synthetic products industries.

Naphthas (petroleum distillates, Stoddard solvents)--If industrial naphtha consists primarily of paraffin and/or naphtha hydrocarbons, the naphtha is classified as an aliphatic based on the solvency kauri-butanol test (48).

Petroleum naphthas are composed of approximately 65% hydrocarbons in the five to eight carbon range, while 35% have nine or more carbon atoms. They contain approximately 2% toluene and a maximum of 0.5% benzene. Naphthas consist of approximately 10% aromatics, from 20% to 60% naphthenes, and from 70% to 30% paraffins, depending on whether the naphtha is low naphthenic or high naphthenic (49). According to ASTM Standard D 838, the boiling point range of refined solvent naphthas is 130°C to 145°C and the specific gravity range is from 0.85 to 0.87 (50). This would give naphtha an average molecular weight of 105. Table 12 lists more specifications of naphthas.

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(47) Jacobs, M. B., and L. Scheflan. Chemical Analysis of Industrial Solvents. Interscience Publishers, Inc., New York, New York, 1953. 501 pp.

(48) 1972 Annual Book of ASTM Standards, Standard No. D1133. American Society for Testing and Materials, Philadelphia, Pennsylvania, 1972.

TABLE 12. SPECIFICATIONS FOR SOME NAPHTHAS (33, 34)

	Solvent naphtha				
		Crude			
Property	Refined	Light	Heavy	Stoddard solvent	Petroleum spirits
ASTM designation	D 838	D 839	D 840	D 484	D 235
Specific gravity at 15.5°C	0.850 to 0.870	0.860 to 0.885	0.885 to 0.970		
Distillation, °C:					
5% Recovered	130 minimum	130 minimum	150 to 165		
50% Recovered, maximum				176	176
90% Recovered, maximum	145	160	200	190	190
End point, maximum	155	180	220		
Flash point, minimum, °C				37.7	37.7

Toluene--Toluene ($C_6H_5CH_3$) (methylbenzene or toluol) is a colorless liquid exuding a benzene-like odor. Its boiling point is 110.4°C and its flash point is 4.4°C. It is moderately toxic. Serious effects due to exposure are rare. The maximum allowable concentration is 200 ppm in air (45). Toluene is derived from coal tar, and commercial grades usually contain small amounts of benzene as an impurity. Its cost in 1976 was estimated to be \$0.187/kg (43). It is used as a solvent for the extraction of various materials, as a diluent in cellulose ether lacquers, and in the manufacture of benzoic acid, benzaldehyde, explosives, dyes, and other organic compounds (47).

Hexane--Hexane [$CH_3(CH_2)_4CH_3$] is a colorless liquid having a boiling point of 68.7°C and a vapor pressure of 13.3 kPa at 15.8°C. It has a low toxic hazard rating. Maximum acceptable concentration is 100 ppm in air and 360 mg/m^3 of air. Hexane is used in gasoline manufacture (45). Its cost in 1976 was estimated to be \$0.167/kg (43).

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(49) Boer, H., and P. Van Arkel. Better Gasoline Chromatography. Hydrocarbon Processing, 51(2):80-84, 1972.

(50) 1974 Annual Book of ASTM Standards, Standard D838. American Society for Testing and Materials, Philadelphia, Pennsylvania, 1974.

Mineral spirits--Mineral spirit is also called turpentine substitute, white spirit, or petroluem spirit. It is a clear, water-white refined hydrocarbon solvent with a minimum flash point of 21°C. It has a boiling point in the range of 150°C to 190°C and a density of 0.80. Its toxic hazard rating is considered to be slight to moderate (47).

Xylene--The xylenes [$C_6H_4(CH_3)_2$] are colorless liquids with a boiling range of 138°C to 144°C. The toxicity is comparable to toluene. The maximum allowable concentration of xylene is 200 ppm in air (44). It is used as a solvent for gums and oils and in the manufacture of dyes and other organic substances (46). The cost of xylene in 1976 was estimated at $0.182/kg (43). It is slightly soluble in water and is miscible with absolute alcohol and other common organic solvents (47).

Cyclohexane--Cyclohexane (C_6H_{12}), also known as hexahydrobenzene or hexamethylene, is a colorless mobile liquid giving off a pungent odor. It has a boiling point of 80.7°C and a vapor pressure of 53.2 kPa at 60.8°C. It is moderately toxic. In high concentrations, it may act as a narcotic and/or skin irritant. Maximum allowable concentration is 400 mg/m^3 of air. Cyclohexane is a solvent for resins and rubber. It is also used as a degreasing agent and a paint thinner. It is insoluble in water but is completely miscible with alcohol, ethers, hydrocarbons, chlorinated hydrocarbons, and most other organic solvents (47). Its cost was estimated to be $0.288/kg in 1976 (43).

Benzene--Benzene (C_6H_6) is also called benzol. It is a colorless, clear liquid having a pleasant odor in low concentrations but unpleasant at higher concentrations. Its boiling point is 80.1°C. Since benzene evaporates at room temperature, it is used in industrial processes where the dissolved substances are to be left unchanged. Benzene is used in oil extraction, dyes and dye intermediates, and in the manufacture of paints, varnishes, and stains as well as paint and varnish removers. It is also used to blend motor fuel (47). In 1976 its cost was estimated to be $0.286/kg (43). The toxic hazard rating is high, as delineated in the latest Occupation Safety and Health Emergency Temporary Standards (51).

Stabilizers--
Stabilizers are added to those solvents that are not chemically stable under some conditions encountered in vapor degreasing. Stabilizers protect the solvent under adverse conditions such as heat, oxygen, active metal chips and fines, acidic salts, alkaline and acidic metal working lubricants, and moisture that may

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(51) Emergency Temporary Standard for Occupational Exposure to Benzene, Notice of Hearing. Federal Register, 42(85)22516-22529, May 3, 1977.

occur. A list of stabilizers used with halogenated solvents is provided in Appendix D.

GEOGRAPHIC DISTRIBUTION

Degreasers

Since there is no degreasing industry per se, degreaser sites have been located by identifying the industries with which they are associated. A sample calculation of how these distributions were determined is presented in Appendix F.

Vapor Degreasers--
In 1972 approximately 24,145 vapor degreasing operations existed. More than 63% of these operations were found in nine states (California, Illinois, Massachusetts, Michigan, New Jersey, New York, Ohio, Pennsylvania, and Texas). The balance of the plants were located in 40 of the remaining 41 states.

Figure 18 represents the geographic distribution of vapor degreasing operations. Table 13 (1-12, 14, 52) summarizes by state the number of such operations.

Cold Cleaning--
The 924,312 plants that performed degreasing in 1972 used 1,220,555 cold cleaning operations. More than half (54%) of

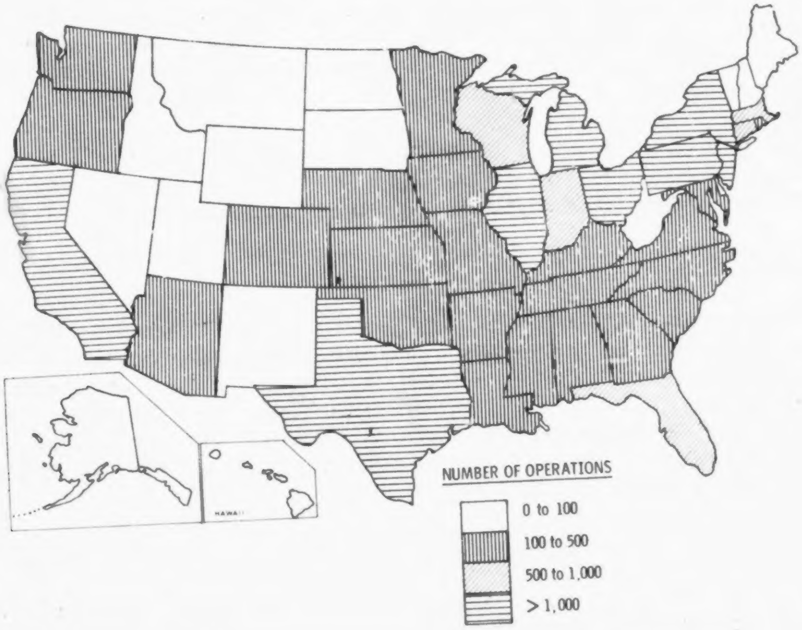

Figure 18. Geographic distribution of vapor degreasing operations.

TABLE 13. GEOGRAPHIC DISTRIBUTION OF VAPOR (OPEN TOP AND CONVEYORIZED) DEGREASING OPERATIONS (1-12, 14, 52)

State	Number of plants	State	Number of plants
Alabama	247	Montana	25
Alaska	0	Nebraska	102
Arizona	169	Nevada	30
Arkansas	147	New Hampshire	96
California	3,313	New Jersey	1,200
Colorado	219	New Mexico	64
Connecticut	648	New York	2,514
Delaware	29	North Carolina	407
District of Columbia	11	North Dakota	20
Florida	730	Ohio	1,576
Georgia	315	Oklahoma	255
Hawaii	29	Oregon	246
Idaho	39	Pennsylvania	1,346
Illinois	1,737	Rhode Island	321
Indiana	688	South Carolina	143
Iowa	225	South Dakota	25
Kansas	217	Tennessee	356
Kentucky	193	Texas	1,119
Louisiana	174	Utah	99
Maine	65	Vermont	39
Maryland	227	Virginia	218
Massachusetts	923	Washington	314
Michigan	1,589	West Virginia	88
Minnesota	426	Wisconsin	604
Mississippi	116	Wyoming	7
Missouri	455	Total	24,145

these operations were located in nine states: California, Florida, Illinois, Michigan, New Jersey, New York, Ohio, Pennsylvania, and Texas. The rest of the plants were located in the other states.

Figure 19 illustrates the geographic distribution of the locations of cold cleaning operations. Table 14 (1-12, 14, 52) summarizes by state the number of such operations.

Fabric Scourers

In 1972 there were approximately 7,201 plants using cold cleaning operations for fabric scouring. More than 90% of these plants were located in 15 states: Alabama, California, Connecticut, Florida, Georgia, Illinois, Massachusetts, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, Tennessee, and Virginia. The remaining 10% of the plants were located in the other 35 states.

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(52) Hughes, T. W., et al. Source Assessment: Prioritization of Air Pollution for Industrial Surface Coating Operations. EPA-650/2-75-019-a, U.S. Environmental Protection Agency, Raleigh, North Carolina, February 1975. 303 pp.

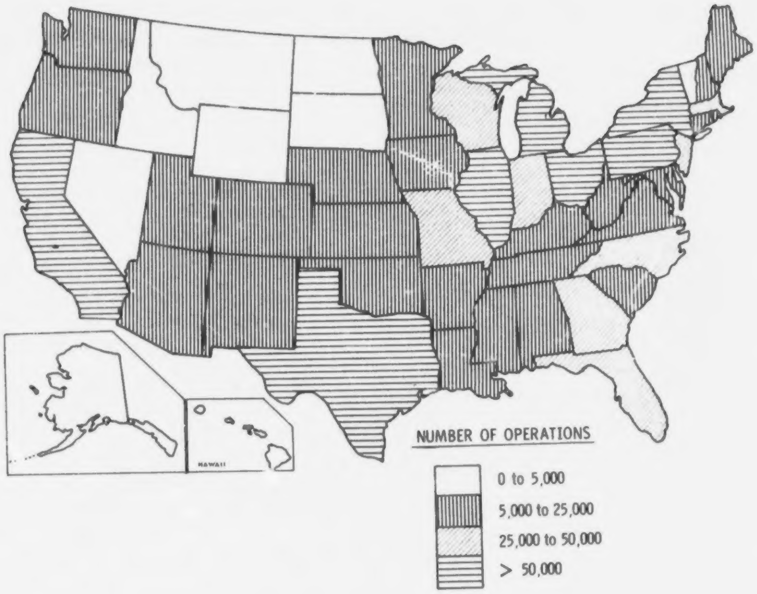

Figure 19. Geographic distribution of cold cleaning operations.

TABLE 14. GEOGRAPHIC DISTRIBUTION OF ALL COLD CLEANING OPERATIONS (1-12, 14, 52)

State	Number of plants	State	Number of plants
Alabama	19,163	Montana	4,003
Alaska	1,295	Nebraska	8,442
Arizona	10,063	Nevada	2,791
Arkansas	11,302	New Hampshire	5,046
California	130,725	New Jersey	47,967
Colorado	13,021	New Mexico	5,492
Connecticut	21,163	New York	113,843
Delaware	2,608	North Carolina	32,270
District of Columbia	2,514	North Dakota	2,880
Florida	41,646	Ohio	65,533
Georgia	28,479	Oklahoma	14,581
Hawaii	3,137	Oregon	15,049
Idaho	4,492	Pennsylvania	67,320
Illinois	68,565	Rhode Island	8,837
Indiana	31,100	South Carolina	14,789
Iowa	16,416	South Dakota	2,185
Kansas	13,460	Tennessee	22,989
Kentucky	15,525	Texas	66,632
Louisiana	16,884	Utah	6,322
Maine	6,432	Vermont	2,893
Maryland	16,884	Virginia	21,697
Massachusetts	36,593	Washington	20,298
Michigan	56,667	West Virginia	8,324
Minnesota	22,690	Wisconsin	28,427
Mississippi	11,442	Wyoming	2,099
Missouri	27,580	Total	1,220,555

Figure 20 depicts the location by state of fabric scouring operations. Table 15 (1, 14, 53-69) summarizes this information.

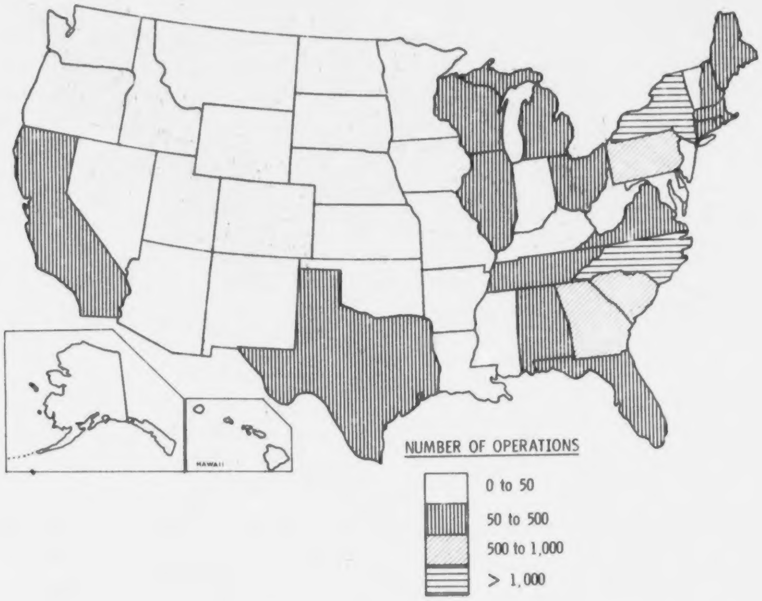

Figure 20. Geographic distribution of fabric scouring operations.

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(53) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2221), Weaving Mills, Manmade Fiber and Silk. MC72(P)-22A-2, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., March 1974. 7 pp.

(54) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2231), Weaving and Finishing Mills, Wool. MC72(P)-22A-3, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., March 1974. 7 pp.

(55) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2241), Narrow Fabric Mills. MC72(P)-22A-4, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., December 1973. 7 pp.

(56) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2211), Weaving Mills, Cotton. MC72(P)-22A-1, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., March 1974. 10 pp.

(57) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2251), Women's Hosiery, Except Socks. MC72(P)-22B-1, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., January 1974. 7 pp.

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(58) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2252), Hosiery, N.E.C. MC72(P)-22B-2, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., February 1974. 7 pp.

(59) 1972 Census of Manfactures, Industry Series, Preliminary Report (SIC 2253), Knit Outerwear Mills. MC72(P)-22B-3, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., March 1974. 7 pp.

(60) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2254), Knit Underwear Mills. MC72(P)-B-4, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., January 1974. 7 pp.

(61) 1972 Census of Manufactures. Industry Series, Preliminary Report (SIC 2257), Circular Knit Fabric Mills. MC72(P)-22B-5, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., January 1974. 7 pp.

(62) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2258), Warp Knit Fabric Mills. MC72(P)-22B-6, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., January 1974. 7 pp.

(63) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2259), Knitting Mills, N.E.C. MC72(P)-22B-7, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., December 1973. 6 pp.

(64) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2261), Finishing Plants, Cotton. MC72(P)-22C-1, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., March 1974. 7 pp.

(65) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2261), Finishing Plants, Man-Made Fiber and Silk Fabric. MC72(P)-22C-2, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., March 1974. 7 pp.

(66) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2269), Finishing Plants, N.E.C. MC72(P)-22C-5, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., March 1974. 6 pp.

(67) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2272), Tufted Carpets and Rugs. MC72(P)-22D-2, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., December 1973. 6 pp.

(68) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2281), Yarn Mills, Except Wool. MC72(P)-22E-1, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., March 1974. 7 pp.

(69) 1972 Census of Manufactures, Industry Series, Preliminary Report (SIC 2282), Throwing and Winding Mills. MC72(P)-22E-2, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., March 1974. 6 pp.

TABLE 15. GEOGRAPHIC DISTRIBUTION OF FABRIC SCOURING OPERATIONS (1, 14, 53-69)

State	Number of plants	State	Number of plants
Alabama	199	Montana	0
Alaska	0	Nebraska	7
Arizona	0	Nevada	22
Arkansas	24	New Hampshire	85
California	351	New Jersey	761
Colorado	14	New Mexico	4
Connecticut	156	New York	1,778
Delaware	12	North Carolina	1,832
District of Columbia	0	North Dakota	0
Florida	109	Ohio	94
Georgia	718	Oklahoma	20
Hawaii	0	Oregon	27
Idaho	3	Pennsylvania	844
Illinois	130	Rhode Island	333
Indiana	21	South Carolina	571
Iowa	13	South Dakota	0
Kansas	0	Tennessee	225
Kentucky	30	Texas	98
Louisiana	16	Utah	9
Maine	64	Vermont	18
Maryland	39	Virginia	144
Massachusetts	428	Washington	22
Michigan	54	West Virginia	9
Minnesota	25	Wisconsin	77
Mississippi	45	Wyoming	1
Missouri	35	Total	9,451

SECTION 4

EMISSIONS

SELECTED POLLUTANTS

This assessment is concerned strictly with emissions resulting from the degreasing operation. Indirect emissions, such as solvent evaporation from wastewater and sludge, solvent reclaiming, and ultimate waste solvent disposal, are not addressed in this report. Emissions from solvent reclaiming are addressed in a separate assessment (70). The pollutants considered during this study are listed in Table 16 along with the corresponding threshold limit values, reactivities, and health effects.

TABLE 16. SELECTED POLLUTANTS AND THEIR THRESHOLD LIMIT VALUES, HEALTH EFFECTS, AND ATMOSPHERIC REACTIVITIES

Solvent	TLV (46) g/m^3	Atmospheric reactivity	Health effects
Butanol	0.30	Contributes to photochemical smog.	Irritation to the eyes, nose, and throat.
Acetone	2.4	"	Narcotic in high concentrations.
Methyl ethyl ketone	0.59	"	Vocal irritation and narcosis.
Hexane	0.36	"	
Naphthas	0.94	"	Ingestion causes vomiting, diarrhea, and drowsiness. Inhalation causes intoxication.
Mineral spirits	0.56	"	
Toluene	0.375	"	Inhalation causes impairment of coordination and reaction time.
Xylene	0.435	"	
Cyclohexane	1.05	"	Skin irritation; simple asphyxiant.
Benzene	0.03	"	Poisoning through vapor inhalation. Recognized carcinogen of blood-forming tissues.
Ethers	1.2	"	Powerful narcotic.
Carbon tetrachloride	0.065	"	Suspected carcinogen.
Fluorocarbons	5.6	Depletes the ozone layer.	Simple asphyxiant.
Methylene chloride	0.72	Contributes to photochemical smog.	Dangerous to the eyes; induces narcosis.
Perchloroethylene	0.67	"	Toxic by inhalation; affects nervous system.
Trichloroethylene	0.67	"	Inhalation of high concentrations causes narcosis and anesthesia.
Trichloroethane	1.9	"	Narcotic in high concentrations.

Note.—Blanks indicate no specific information found.

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(70) Tierney, D. R., and T. W. Hughes. Source Assessment: Reclaiming of Waste Solvents, State of the Art. Contract 68-02-1874, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. (Preliminary document submitted to the EPA by Monsanto Research Corporation.) 58 pp.

LOCATION AND DESCRIPTION OF EMISSION POINTS

Cold Cleaners

The emission points from a cold cleaner are 1) bath evaporation, 2) solvent carryout, 3) agitation, and 4) spray evaporation. These emission points are depicted in Figure 21 (71).

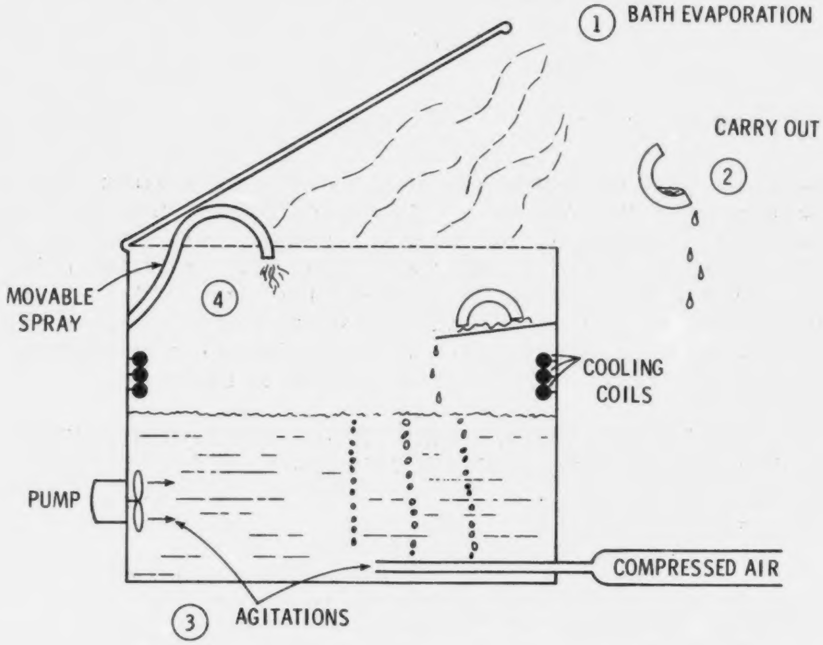

Figure 21. Cold cleaner emission points.

Bath evaporation occurs from the solvent surface and from exposed wet surfaces inside the cleaning tank. Evaporation is greatest when highly volatile solvents are used and when the cover is open. Solvent heating also increases the bath evaporation. In addition, excessive drafts in the workshop area will increase evaporation emissions.

Carryout solvent is the solvent that resides on and exits with the cleaned part. This liquid solvent eventually evaporates into the atmosphere except for those drippings which are captured by means of a drainage facility and reused. The less volatile solvents are more likely to be emitted by means of liquid carryout.

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(71) Control of Volatile Organic Emissions from Organic Solvent Metal Cleaning Operations (draft document). U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1977. pp. 2-11.

Agitation increases the evaporation rate from the bath, in some cases significantly. The evaporation rate from all types of agitation increases with the volatility of the solvent (at the operating temperature). Emissions from agitation are negligible when the cover is closed.

The last emission point in cold cleaning is solvent spray evaporation. Evaporation from solvent spraying will increase with the pressure of the spray, the fineness of the spray, the tendency to splash, and overspray out of the tank.

One-half to three-fourths of the cold cleaner solvent is estimated to be emitted from waste solvent evaporation (72).

Open Top Vapor Degreasers

Unlike cold cleaners, open top vapor degreasers emit a relatively small (approximately 25%) proportion of their solvent as waste material and/or liquid carryout. Emissions from open top vapor degreasing are the vapors that diffuse and convect out of the degreaser.

Emissions from open top vapor degreasers come from 1) diffusion, 2) carryout, and 3) exhaust. The first two of these are the most important. These emission points are depicted in Figure 22 (73).

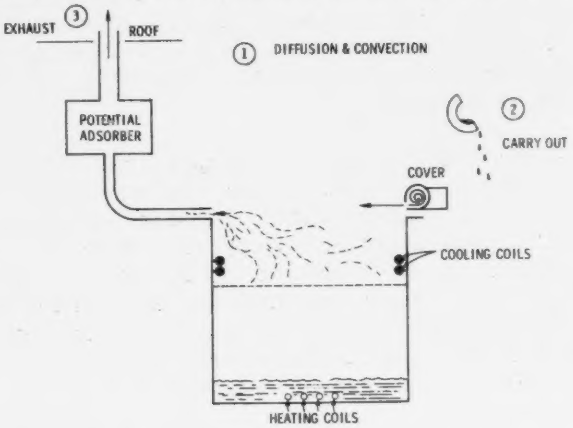

Figure 22. Open top vapor degreaser emission points (73).

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(72) Control of Volatile Organic Emissions from Organic Solvent Metal Cleaning Operations (draft document). U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1977. pp. 2-12.

(73) Control of Volatile Organic Emissions from Organic Solvent Metal Cleaning Operations (draft document). U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1977. pp. 2-29.

Diffusion is the escaping of solvent vapors from the vapor zone out of the degreaser. There is an air/vapor interface at the top of the vapor zone where the solvent mixes with air. This mixing increases with drafts and with disturbances from cleaned parts being moved in and out of the vapor zone. The solvent vapors thus diffuse into the room air and into the atmosphere. These solvent losses include the convection of warm solvent-laden air upwards out of the degreaser.

Solvent vapors should be generated at the same rate at which they are condensed by work entering the vapor zone. If too little vapor is generated, the vapor level will drop and air will be drawn into the degreaser. The resulting air-vapor mixture is more easily swept from the machine by drafts. If too much vapor is generated, the vapor level will rise above the condensing coils and vapor will escape from the machine.

Emissions from the degreaser top include the solvent, solvent stabilizers, and the grease or oil removed from the parts being degreased.

Carryout emissions are the liquid and vaporous solvent entrained on the clean parts as they are taken out of the degreaser. Crevices and cupped portions of the cleaned parts may capture liquid and vaporous solvents even after the parts appear to be dried. Furthermore, as the cleaned part is drawn out of the vapor zone, it drags up solvent vapors. Simultaneously, the hot, cleaned part heats solvent-laden air, causing it to convect upwards out of the degreaser.

Exhaust systems are often used on large, open top vapor degreasers. The exhaust system draws in solvent-laden air around the top perimeter of the degreaser. These exhaust systems are called lip or lateral exhausts. When the exhaust rate is appreciably larger than that necessary to provide for operator safety and plant protection, solvent emissions are increased. Some systems include carbon adsorbers to collect the exhausted solvent for reuse; exhausted emissions are thus nearly eliminated if the adsorption system is operated properly.

Indirect solvent emissions also result from disposing of waste solvent in ways where the solvent can evaporate into the atmosphere. The volume of waste solvent from vapor degreasers is less than that from cold cleaners for the same size workload because the solvent in a vapor degreaser may be used for a longer time. Vapor degreasing wastes can contain from 15% to 30% oil contamination, whereas cold cleaning waste solvent can only contain about 10% oil contamination before it must be replaced. Vapor degreasing solvents are halogenated and, as such, are generally less flammable and more expensive; thus, they are more often distilled and recycled than cold cleaning solvents.

Conveyorized Degreasers

Conveyorized degreasers have the same basic emissions associated with open top vapor degreasers: 1) diffusion from the solvent bath, 2) carryout, and 3) exhausted vapors. These points are depicted in Figure 23 (74).

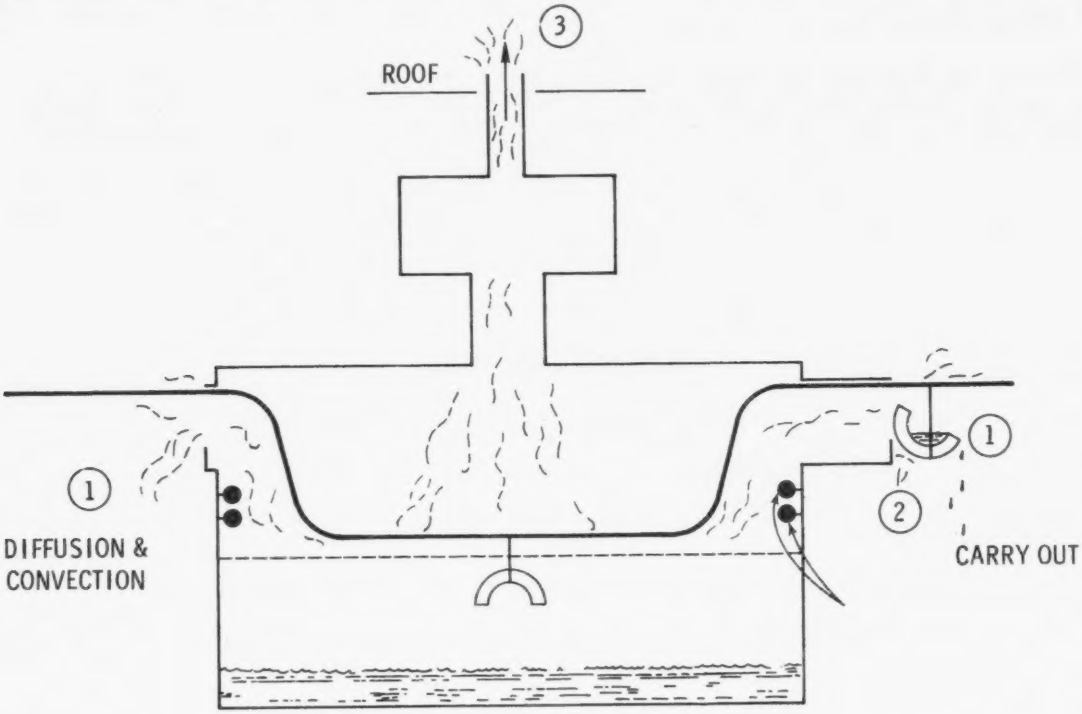

Figure 23. Conveyorized degreaser emission points (74).

The diffusion and convection of solvent vapors from the solvent bath are less for conveyorized degreasers than for open top degreasers for an equivalent workload because the conveyorized degreasers are normally enclosed except for a relatively small entrance and exit.

Carryout emissions of vapor and liquid solvent are usually the major emission point from conveyorized degreasers. Reducing carryout emissions is difficult, because the amount of workload is inherently large.

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(74) Control of Volatile Organic Emissions from Organic Solvent Metal Cleaning Operations (draft document). U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1977. pp. 2-45.

Evaporation from waste solvent disposal is the smallest indirect emission from conveyorized degreasers. Conveyorized degreasers are designed to distill their own solvent. An external still is attached to the degreaser so that it consistently pumps out used solvent, distills it, and returns it. Thus the disposed waste solvent is the still bottoms.

Fabric Scourers

Fabric scouring processes have three points of emissions. Figure 24, a sketch of a fabric scourer, identifies these three points, and Table 17 lists them. Each is discussed separately.

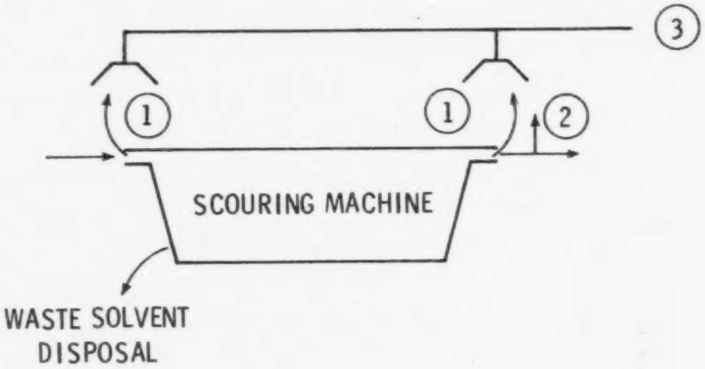

Figure 24. Fabric scourer emission points.

TABLE 17. FABRIC SCOURER EMISSION POINTS

1. Inlet and outlet losses.
2. Dragout.
3. Ventilator exhaust.

Inlet and Outlet Losses (Emission Point 1)--

Fabric scouring machines are enclosed so that the only sources of emissions from the machine itself are the inlet and outlet openings.

Solvent Dragout (Emission Point 2)--

The fabric leaving the dryer section of the scouring machine contains unevaporated solvent. All of this solvent eventually is emitted to the atmosphere if not collected by a drainage trap.

Ventilator Exhaust (Emission Point 3)--

Emissions from the scourer inlet and outlet may be collected by a ventilation system. Exhaust from this system is sent either directly to the atmosphere or to a carbon adsorption system. If the scourer has an adsorption system, exhaust from the bed will be emitted to the atmosphere.

EMISSION FACTORS

Emission factors for degreasing operations are calculated by determining the difference between the total amount of solvent utilized in the specific type of operation and the amount accountable through degreaser waste solvent activities.

Solvent consumption and the portion used in degreasing (cold cleaning, open top vapor degreasing, conveyorized vapor degreasing) and fabric scouring were presented in Table 11. The percentages and quantities of solvent used in degreasing and fabric scouring that leave the operation as waste solvent are listed in Table 18. The resultant emission factors for each type of degreasing operation are presented in Table 19. Insufficient data precluded the calculation of an emission factor on a solvent-by-solvent basis. Thus all solvents utilized within a specific degreasing operation are assumed to have the emission factor calculated for that operation.

TABLE 18. WASTE SOLVENT GENERATION BY TYPE OF DEGREASING OPERATION

Degreasing operation	Total solvent consumption, that becomes waste solvent, %[a] Range	Average	Total waste solvent, 10^3 metric tons/yr
Cold cleaners:			
Manufacturing (44%)	40 to 60	50.0	103.7
Maintenance (56%)	50 to 75	62.5	165.0
Open top vapor degreasers	20 to 25	22.5	43.66
Conveyorized vapor degreasers	10 to 20	15.0	10.9
Fabric scourers[b]	40 to 60	50	102.30

[a] Personal communication, J. L. Shumaker.

[b] Assumed a conveyorized cold cleaner.

TABLE 19. EMISSION FACTORS FOR DEGREASING OPERATION TYPES

Degreasing operation	Total emissions (solvent input - waste solvent), 10^3 metric tons/yr	Emission factor, g/kg solvent consumed
Cold cleaning	203.10[a]	430 ± 30%[b]
Open top vapor degreasing	150.8	775 ± 30%[b]
Conveyorized vapor degreasing	61.3	850 ± 30%[b]
Fabric scouring	102.3	500 ± 30%[b]

[a] [Total cold cleaning solvent consumption - waste solvent (maintenance cold) - waste solvent (manufacturing cold)] ÷ total cold cleaning solvent consumption.

$$[471.32 \times 10^3 - 164.96 \times 10^3 - 103.69 \times 10^3] \div 471.32 \times 10^3 = \frac{0.430 \text{ metric ton}}{\text{metric ton}}$$

[b] Personal communication, J. L. Shumaker.

DEFINITION OF A REPRESENTATIVE SOURCE

A representative degreasing operation was determined for each solvent type and for each degreasing type by calculating average degreaser solvent consumption, average stack height, frequency of operation, and average emission rate. Average degreaser solvent consumption was calculated by dividing total solvent consumption by the number of degreasers for each degreasing type. Average stack height and frequency of operation were determined from data obtained from the National Emissions Data System (NEDS) (75). These data are presented in Appendix E of this report.

Average emission rate was obtained by multiplying average solvent consumption by the appropriate emission factor, and dividing by the frequency of operation and by seconds per year. The resulting emission rates and supporting input data are presented in Tables 20 through 23. Sample calculations are presented in Appendix B.

TABLE 20. CHARACTERISTICS OF EMISSIONS FROM REPRESENTATIVE COLD CLEANING OPERATIONS

Solvent	Average degreaser size, kg solvent consumed/yr	Average height, m	Frequency of operation, %	Emission rate, g/s
Butanol	53.6	10.6	65	0.0011
Acetone	126.3	10.6	65	0.0027
Methyl ethyl ketone	177.6	10.6	65	0.0037
Hexane	420.6	10.6	65	0.0088
Naphthas	454.7	10.6	65	0.0096
Mineral spirits	420.6	10.6	65	0.0088
Toluene	256.6	10.6	65	0.0054
Xylenes	420.6	10.6	65	0.0088
Cyclohexane	420.6	10.6	65	0.0088
Benzene	420.6	10.6	65	0.0088
Ethers	3,410.2	10.6	65	0.0715
Carbon tetrachloride	68.2	10.6	65	0.0014
Fluorocarbons	89.7	10.6	65	0.0019
Methylene chloride	2,187.8	12.1	80	0.0373
Perchloroethylene	249.2	10.7	78	0.0044
Trichloroethylene	292.8	12	78	0.0051
Trichloroethane	568.2	14.1	96	0.0081

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(75) National Emissions Data System (NEDS) via Aerometric and Emissions Reporting System (AEROS). U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

TABLE 21. CHARACTERISTICS OF EMISSIONS FROM REPRESENTATIVE OPEN TOP VAPOR DEGREASING OPERATIONS

Solvent	Average degreaser size, kg solvent consumed/yr	Average height, m	Frequency of operation, %	Emission rate, g/s
Fluorocarbons	3,806	10.6	65	0.1439
Methylene chloride	24,518	12.1	80	0.7532
Perchloroethylene	10,070	10.7	78	0.3173
Trichloroethylene	7,165	12.0	78	0.2257
Trichloroethane	16,394	14.1	96	0.4197

TABLE 22. CHARACTERISTICS OF EMISSIONS FROM REPRESENTATIVE CONVEYORIZED VAPOR DEGREASING OPERATIONS

Solvent	Average degreaser size, kg solvent consumed/yr	Average height, m	Frequency of operation, %	Emission rate, g/s
Fluorocarbons	9,403	10.6	65	0.3899
Methylene chloride	60,053	12.1	80	2.0233
Perchloroethylene	24,883	10.7	78	0.8598
Trichloroethylene	17,780	12.0	78	0.6144
Trichloroethane	40,468	14.1	96	1.1362

TABLE 23. CHARACTERISTICS OF EMISSIONS FROM REPRESENTATIVE FABRIC SCOURING OPERATIONS

Solvent	Average scourer, kg solvent consumed/yr	Average height, m	Frequency of operation, %	Emission rate, g/s
Benzene	21,664	10.6	65	0.5284
Xylene	21,664	10.6	65	0.5284
Perchloroethylene	21,664	10.7	78	0.4404
Trichloroethylene	21,664	12.0	78	0.4404

CRITERIA FOR AIR EMISSIONS

Maximum Ground Level Concentration

The maximum ground level concentration (χ_{max}) of each material emitted from each type of degreasing operation was calculated by Gaussian plume dispersion modeling. The following formula was used for calculating χ_{max} (76):

$$\chi_{max} = \frac{2\,Q_m}{\pi e h^2 \overline{u}} \qquad (1)$$

where Q_m = mass emission rate, g/s
$\overline{u}$ = average wind speed = 4.5 m/s
h = height of the solvent emissions, m
e = 2.72
π = 3.14

Source Severity

To assess the environmental impact of atmospheric emissions from degreasing operations, the source severity of each solvent emitted from each type of degreasing operation was estimated. Source severity is defined as the pollutant concentration to which the population may be exposed divided by an "acceptable concentration." The exposure concentration is the time-averaged maximum ground level concentration as determined by Gaussian plume dispersion methodology. The "acceptable concentration" is that pollutant concentration at which an incipient adverse health effect is assumed to occur. For criteria pollutants, it is the corresponding primary ambient air quality standard.[a] For non-criteria pollutants, it is a surrogate air quality standard as determined by reducing TLV's for chemical substances using an appropriate safety factor. Mathematically, the source severity, S, was defined as:

$$S = \frac{\overline{\chi}_{max}}{F} \qquad (2)$$

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[a] There is no primary ambient air quality standard for hydrocarbons. The value of 160 $\mu g/m^3$ used for hydrocarbons in this report is a recommended guideline for meeting the primary ambient air quality standard for photochemical oxidants.

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(76) Turner, D. B. Workbook of Atmospheric Dispersion Estimates. Public Health Service Publication No. 999-AP-26. U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, May 1970. 84 pp.

where $\bar{\chi}_{max}$ = time-averaged maximum ground level concentration
F = hazard factor, equal to the primary ambient air quality standard (AAQS) for particulate, sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide ($\overline{CO}$), and hydrocarbons,[a] and equal to TLV x 8/24 x 1/100 for all other chemical substances

$\bar{\chi}_{max}$ was calculated using the formula (76, 77)

$$\bar{\chi}_{max} = \chi_{max} \left(\frac{t_o}{t}\right)^{0.17} \tag{3}$$

where χ_{max} = maximum ground level concentration
t_o = short-term averaging time, 3 min
t = averaging time, min

For hydrocarbons, averaging time is the same as that used in the primary ambient air quality standards ($t_o/t = 3/180$). The appropriate averaging time was 24 hr for all other pollutants (e.g., $t_o/t = 3/1440$). Source severity equations are derived in Appendix A.

The value of $\bar{\chi}_{max}$ for each material emitted from each representative degreasing type is presented in Tables 24 through 27 along with the calculated source severity based on the AAQS and the TLV for each solvent emitted.

TABLE 24. TIME-AVERAGED MAXIMUM GROUND LEVEL CONCENTRATIONS AND SOURCE SEVERITIES FOR REPRESENTATIVE COLD CLEANING OPERATIONS

Solvent	Emission rate, g/s	TLV, g/m^3	$\bar{\chi}_{max}$, g/m^3 AAQS basis	$\bar{\chi}_{max}$, g/m^3 TLV basis	S_{TLV}	S_{AAQS}
Butanol	0.0011	0.3	2.5×10^{-7}	1.8×10^{-7}	1.8×10^{-4}	1.6×10^{-3}
Acetone	0.0027	2.4	6.2×10^{-7}	4.4×10^{-7}	5.5×10^{-5}	3.9×10^{-3}
Methyl ethyl ketone	0.0037	0.59	8.5×10^{-7}	6.0×10^{-7}	3.0×10^{-4}	5.3×10^{-3}
Hexane	0.0088	0.36	2.0×10^{-6}	1.4×10^{-6}	1.2×10^{-3}	1.3×10^{-2}
Naphthas	0.0096	0.94	2.1×10^{-6}	1.5×10^{-6}	5.0×10^{-4}	1.4×10^{-2}
Mineral spirits	0.0088	0.56	2.0×10^{-6}	1.4×10^{-6}	7.6×10^{-4}	1.3×10^{-2}
Toluene	0.0054	0.375	1.2×10^{-6}	8.7×10^{-7}	7.0×10^{-4}	7.8×10^{-3}
Xylene	0.0088	0.436	2.0×10^{-6}	1.4×10^{-6}	9.8×10^{-4}	1.3×10^{-2}
Cyclohexane	0.0088	1.05	2.0×10^{-6}	1.4×10^{-6}	4.1×10^{-4}	1.3×10^{-2}
Benzene	0.0088	0.03	2.0×10^{-6}	1.4×10^{-6}	1.4×10^{-2}	1.3×10^{-2}
Ether	0.0715	1.2	1.7×10^{-5}	1.2×10^{-5}	2.9×10^{-3}	9.3×10^{-2}
Carbon tetrachloride	0.0014	0.065	3.3×10^{-7}	2.3×10^{-7}	1.0×10^{-3}	2.0×10^{-3}
Fluorocarbons	0.0019	5.6	4.4×10^{-7}	3.1×10^{-7}	1.2×10^{-5}	2.7×10^{-3}
Methylene chloride	0.0373	0.72	6.5×10^{-6}	4.6×10^{-6}	1.9×10^{-3}	4.1×10^{-2}
Perchloroethylene	0.0044	0.67	9.5×10^{-7}	6.7×10^{-7}	3.1×10^{-4}	6.2×10^{-3}
Trichloroethylene	0.0051	0.535	9.1×10^{-7}	6.4×10^{-7}	3.6×10^{-4}	5.7×10^{-3}
1,1,1-Trichloroethane	0.0081	1.9	1.0×10^{-6}	7.4×10^{-7}	1.2×10^{-4}	6.6×10^{-3}

TABLE 25. TIME-AVERAGED MAXIMUM GROUND LEVEL CONCENTRATIONS AND SOURCE SEVERITIES FOR REPRESENTATIVE OPEN TOP VAPOR DEGREASING OPERATIONS

Solvent	Emission rate, g/s	TLV, g/m^3	$\bar{X}_{max}$, g/m^3 AAQS basis	$\bar{X}_{max}$, g/m^3 TLV basis	S_{TLV}	S_{AAQS}
Fluorocarbons	0.1439	5.6	3.3×10^{-5}	2.3×10^{-5}	9.2×10^{-4}	0.208
Methylene chloride	0.7532	0.72	1.3×10^{-4}	9.4×10^{-5}	3.9×10^{-2}	0.836
Perchloroethylene	0.3173	0.67	7.1×10^{-5}	5.0×10^{-5}	2.3×10^{-2}	0.450
Trichloroethylene	0.2257	0.535	4.1×10^{-5}	2.8×10^{-5}	1.6×10^{-2}	0.255
Trichloroethane	0.4197	1.9	5.4×10^{-5}	3.8×10^{-5}	6.1×10^{-3}	0.343

TABLE 26. TIME-AVERAGED MAXIMUM GROUND LEVEL CONCENTRATIONS AND SOURCE SEVERITIES FOR REPRESENTATIVE CONVEYORIZED VAPOR DEGREASING OPERATIONS

Solvent	Emission rate, g/s	TLV g/m^3	$\bar{X}_{max}$, g/m^3 AAQS basis	$\bar{X}_{max}$, g/m^3 TLV basis	S_{TLV}	S_{AAQS}
Fluorocarbons	0.3899	5.6	8.9×10^{-5}	6.3×10^{-5}	2.49×10^{-3}	0.564
Methylene chloride	2.0233	0.72	3.5×10^{-4}	2.5×10^{-4}	1.05×10^{-1}	2.246
Perchloroethylene	0.8598	0.67	2.0×10^{-4}	1.4×10^{-4}	6.1×10^{-2}	1.22
Trichloroethylene	0.6144	0.535	1.1×10^{-4}	7.8×10^{-5}	4.6×10^{-2}	0.693
1,1,1-trichloroethane	1.1362	1.9	1.4×10^{-4}	1.0×10^{-4}	1.6×10^{-2}	0.929

TABLE 27. TIME-AVERAGED MAXIMUM GROUND LEVEL CONCENTRATIONS AND SOURCE SEVERITIES FOR REPRESENTATIVE FABRIC SCOURING OPERATIONS

Solvent	Emission rate, g/s	TLV g/m^3	$\bar{X}_{max}$, g/m^3 AAQS basis	$\bar{X}_{max}$, g/m^3 TLV basis	S_{TLV}	S_{AAQS}
Benzene	0.5284	0.03	1.2×10^{-4}	8.5×10^{-5}	0.856	0.764
Xylenes	0.5284	0.436	1.2×10^{-4}	8.5×10^{-5}	0.059	0.764
Perchloroethylene	0.4404	0.67	1.0×10^{-4}	7.0×10^{-5}	0.031	0.625
Trichloroethylene	0.4404	0.535	7.9×10^{-5}	5.6×10^{-5}	0.031	0.497

Contribution to State and Total U.S. Hydrocarbon Emissions

The contribution of the emissions from various types of degreasing operations to individual state and total U.S. hydrocarbon emissions from stationary sources was determined utilizing the geographical distribution of degreasing operations presented in Tables 13 through 15 and the average mass emission rate per degreaser type presented in Table 28. Tables 29 through 32 (78) list the results. It is estimated that 3.12% of the hydrocarbon emissions in the United States come from degreasing operations described in this report.

TABLE 28. AVERAGE MASS EMISSIONS PER DEGREASER BY TYPE OF DEGREASING OPERATION

Degreaser type	Total mass emissions, metric tons/yr (1974 basis)	Number of operations	Average mass emissions per degreaser, metric tons/yr
Cold cleaning	2.03×10^5	1,220,555	0.17
Open top vapor degreasing	1.51×10^5	21,000	7.19
Conveyorized vapor degreasing	6.13×10^4	3,145	19.49
Fabric scouring	1.02×10^5	9,451	10.82

TABLE 29. CONTRIBUTION OF COLD CLEANING EMISSIONS TO TOTAL STATE AND U.S. HYDROCARBON EMISSIONS FROM STATIONARY SOURCES

State	Number of cold cleaning operations	1974 Hydrocarbon emissions from cold cleaning, metric tons	Total state hydrocarbon emissions (78), metric tons	Percent of state hydrocarbon emissions
Alabama	19,163	3,186.8	226,700	1.4
Alaska	1,245	207.0	33,000	0.6
Arizona	10,003	1,663.5	98,840	1.7
Arkansas	11,302	1,879.5	136,400	1.4
California	130,575	21,714.6	1,423,000	1.5
Colorado	13,011	2,163.7	145,600	1.5
Connecticut	21,103	3,509.4	207,400	1.7
Delaware	2,600	432.4	65,960	0.6
District of Columbia	2,514	418.1	0	0
Florida	41,596	6,917.4	426,900	1.6
Georgia	28,439	4,729.4	321,800	1.5
Hawaii	3,137	521.7	52,910	1.0
Idaho	4,492	747.0	57,480	1.3
Illinois	68,485	11,389.1	828,600	1.4
Indiana	31,100	5,171.9	419,700	1.2
Iowa	16,416	2,730.0	187,400	1.5
Kansas	13,450	2,236.7	239,700	0.9
Kentucky	15,525	2,581.8	229,300	1.1
Louisiana	16,844	2,801.1	1,008,000	0.3
Maine	6,432	1,069.6	57,100	1.9
Maryland	16,844	2,801.1	244,500	1.1
Massachusetts	36,543	6,077.1	368,400	1.6
Michigan	56,597	9,412.1	537,300	1.8
Minnesota	22,690	3,773.3	251,100	1.5
Mississippi	11,412	1,897.8	209,500	0.9
Missouri	27,560	4,583.2	309,900	1.5
Montana	4,003	665.7	82,820	0.8
Nebraska	8,422	1,400.6	102,400	1.4
Nevada	2,771	460.8	23,370	2.0
New Hampshire	5,016	834.2	37,210	2.2
New Jersey	47,907	7,966.9	634,100	1.2
New Mexico	5,492	913.3	115,600	0.8
New York	113,743	18,915.5	1,096,000	1.7
North Carolina	32,210	5,356.5	339,700	1.6
North Dakota	2,880	478.9	39,810	1.2
Ohio	65,458	10,885.7	838,700	1.3
Oklahoma	14,561	2,421.5	241,100	1.0
Oregon	15,049	2,502.6	155,100	1.6
Pennsylvania	67,240	11,182.0	902,200	1.2
Rhode Island	8,837	1,469.6	73,060	2.0
South Carolina	14,769	2,456.1	176,100	1.4
South Dakota	2,185	363.4	35,780	1.0
Tennessee	22,959	3,818.1	258,200	1.5
Texas	66,557	11,068.4	2,184,000	0.5
Utah	6,322	1,051.3	69,930	1.5
Vermont	2,893	481.1	21,100	2.3
Virginia	21,677	3,604.9	270,800	1.3
Washington	20,298	3,375.6	259,200	1.3
West Virginia	8,324	1,384.3	162,300	0.8
Wisconsin	28,427	4,727.4	280,600	1.7
Wyoming	2,099	349.1	97,100	0.4
Total	1,220,555	203,000	16,580,000	1.2

TABLE 30. CONTRIBUTION OF OPEN TOP VAPOR DEGREASING EMISSIONS TO TOTAL STATE AND U.S. HYDROCARBON EMISSIONS FROM STATIONARY SOURCES

State	Number of open top vapor degreasing operations	1974 Hydrocarbon emissions from open top vapor degreasing, metric tons	Total state hydrocarbon emissions (78), metric tons	Percent of state hydrocarbon emissions
Alabama	215	1,539.7	226,700	0.68
Alaska	0	0	33,000	0
Arizona	147	1,052.8	98,840	1.06
Arkansas	128	916.6	136,400	0.67
California	2,881	20,632.8	1,423,000	1.45
Colorado	190	1,360.7	145,600	0.93
Connecticut	564	4,039.2	207,400	1.95
Delaware	25	179	65,960	0.27
District of Columbia	9	64.5		
Florida	635	4,547.6	426,900	1.06
Georgia	274	1,962.3	321,800	0.61
Hawaii	25	179	52,910	0.34
Idaho	34	243.5	57,480	0.42
Illinois	1,511	10,821.3	828,600	1.31
Indiana	598	4,282.7	419,700	1.02
Iowa	196	1,403.7	187,400	0.75
Kansas	189	1,353.5	239,700	0.56
Kentucky	168	1,203.1	229,500	0.52
Louisiana	151	1,081.4	1,008,000	0.11
Maine	56	401	57,100	0.7
Maryland	197	1,410.8	244,500	0.58
Massachusetts	803	5,750.9	368,400	1.56
Michigan	1,382	9,897.4	537,300	1.84
Minnesota	370	2,649.9	251,100	1.05
Mississippi	101	745.9	209,500	0.36
Missouri	396	2,836.1	309,900	0.91
Montana	22	157.6	82,820	0.19
Nebraska	89	637.3	102,400	0.62
Nevada	26	186.2	23,370	0.8
New Hampshire	83	594.5	37,210	1.6
New Jersey	1,044	7,476.8	634,100	1.18
New Mexico	56	401	115,600	0.35
New York	2,186	15,655.4	1,096,000	1.43
North Carolina	354	2,535.2	339,700	0.75
North Dakota	17	121.7	39,810	0.31
Ohio	1,371	9,818.7	838,700	1.17
Oklahoma	222	1,589.9	241,100	0.66
Oregon	214	1,532.6	155,100	0.99
Pennsylvania	1,171	8,385.9	902,200	0.93
Rhode Island	279	1,998.1	73,060	2.73
South Carolina	124	888	176,100	0.50
South Dakota	22	157.6	35,780	0.44
Tennessee	310	2,220.1	258,200	0.86
Texas	973	6,968.3	2,184,000	0.32
Utah	86	615.9	69,930	0.88
Vermont	34	243.5	21,100	1.15
Virginia	190	1,360.7	270,800	0.5
Washington	273	1,955.1	259,200	0.75
West Virginia	76	544.2	162,300	0.33
Wisconsin	525	3,759.9	280,600	1.34
Wyoming	6	43	97,100	0.04
Total	21,000	150,800	16,580,000	0.91

Note.—Blanks indicate no specific information found.

TABLE 31. CONTRIBUTION OF CONVEYORIZED VAPOR DEGREASING EMISSIONS TO TOTAL STATE AND U.S. HYDROCARBON EMISSIONS FROM STATIONARY SOURCES

State	Number of conveyorized vapor degreasing, operations	1974 Hydrocarbon emissions from conveyorized vapor degreasing, metric tons	Total state hydrocarbon emissions (78), metric tons	Percent of state hydrocarbon emissions
Alabama	32	629	226,700	0.27
Alaska	0	0	33,000	0
Arizona	22	432.4	98,840	0.44
Arkansas	19	373.4	136,400	0.27
California	432	8,490	1,423,000	0.6
Colorado	29	570	145,600	0.39
Connecticut	84	1,650.9	207,400	0.8
Delaware	4	78.6	65,960	0.12
District of Columbia	2	39.2		
Florida	95	1,867.3	426,900	0.44
Georgia	41	805.8	321,800	0.25
Hawaii	4	78.6	52,910	0.15
Idaho	5	98.1	57,480	0.17
Illinois	226	4,442	828,600	0.54
Indiana	90	1,768.9	419,700	0.42
Iowa	29	570	187,400	0.3
Kansas	28	550.4	239,700	0.23
Kentucky	25	491.4	229,500	0.21
Louisiana	23	452	1,008,000	0.04
Maine	9	176.8	57,100	0.31
Maryland	30	589.6	244,500	0.24
Massachusetts	120	2,358.6	368,400	0.64
Michigan	207	4,068.6	537,300	0.76
Minnesota	56	1,100	251,100	0.44
Mississippi	15	294.8	209,500	0.14
Missouri	59	1,159	309,900	0.37
Montana	3	59	82,820	0.07
Nebraska	13	255.5	102,400	0.25
Nevada	4	78.6	23,370	0.34
New Hampshire	13	255.5	37,210	0.69
New Jersey	156	3,066.2	634,100	0.48
New Mexico	8	157.2	115,600	0.13
New York	328	6,446.9	1,096,000	0.59
North Carolina	53	1,041	339,700	0.31
North Dakota	3	59	39,810	0.15
Ohio	205	4,029.2	838,700	0.48
Oklahoma	33	648.6	241,100	0.27
Oregon	32	629	155,100	0.4
Pennsylvania	175	3,439.6	902,200	0.38
Rhode Island	42	825.5	73,060	1.13
South Carolina	19	373.4	176,100	0.21
South Dakota	3	59	35,780	0.16
Tennessee	46	904	258,200	0.35
Texas	146	2,869.6	2,184,000	0.13
Utah	13	255.3	69,930	0.36
Vermont	5	98.2	21,100	0.46
Virginia	28	550.4	270,800	0.2
Washington	41	805.8	259,200	0.31
West Virginia	12	235.8	162,300	0.14
Wisconsin	79	1,552.7	280,600	0.55
Wyoming	1	19.6	97,100	0.02
Total	3,145	61,290	16,580,000	0.37

Note.—Blanks indicate data not available.

TABLE 32. CONTRIBUTION OF FABRIC SCOURING EMISSIONS TO TOTAL STATE AND U.S. HYDROCARBON EMISSIONS FROM STATIONARY SOURCES

State	Number of fabric scouring operations	1974 Hydrocarbon emissions from fabric scouring, metric tons	Total state hydrocarbon emissions (78), metric tons	Percent of state hydrocarbon emissions
Alabama	199	2,156	226,700	0.9
Alaska	0	0	33,000	0
Arizona	0	0	98,840	0
Arkansas	24	260	136,400	0.2
California	351	3,803.6	1,423,000	0.3
Colorado	14	151.5	145,600	0.1
Connecticut	156	1,688.6	207,400	0.8
Delaware	12	129.9	65,960	0.2
District of Columbia		0		0
Florida	109	1,179.8	426,900	0.3
Georgia	718	7,780.6	321,800	2.4
Hawaii	0	0	52,910	0
Idaho	3	32.5	57,480	0.06
Illinois	130	1,407.1	828,600	0.2
Indiana	21	227.3	419,700	0.05
Iowa	13	140.7	187,400	0.07
Kansas	0	0	239,700	0
Kentucky	30	324.7	229,500	0.1
Louisiana	16	173.2	1,008,000	0.02
Maine	64	692.7	57,100	1.2
Maryland	39	422.1	244,500	0.2
Massachusetts	428	4638	368,400	1.3
Michigan	54	584.5	537,300	0.1
Minnesota	25	270.6	251,100	0.1
Mississippi	45	487.1	209,500	0.2
Missouri	35	378.8	309,900	0.1
Montana	0	0	82,820	0
Nebraska	7	75.8	102,400	0.07
Nevada	22	238.1	23,370	1.0
New Hampshire	85	920.1	37,210	2.5
New Jersey	761	8,246.6	634,100	1.3
New Mexico	4	43.3	115,600	0.04
New York	1,778	19,267.3	1,096,000	1.8
North Carolina	1,832	19,852.5	339,700	5.8
North Dakota	0	0	39,810	0
Ohio	94	1,017.5	838,700	0.1
Oklahoma	20	216.5	241,100	0.09
Oregon	27	292.2	155,100	0.2
Pennsylvania	844	9,146.1	902,200	1.0
Rhode Island	333	3,604.5	73,060	4.9
South Carolina	571	6,180.6	176,100	3.5
South Dakota	0	0	35,780	0
Tennessee	225	2,435.5	258,200	0.9
Texas	98	1,060.8	2,184,000	0.05
Utah	9	97.4	69,930	0.1
Vermont	18	194.8	21,100	0.9
Virginia	144	1,558.7	270,800	0.6
Washington	22	238.1	259,200	0.09
West Virginia	9	97.4	162,300	0.06
Wisconsin	77	833.5	280,600	0.3
Wyoming	1	10.8	97,100	0.01
Total	9,451	102,357	16,580,000	0.6
Total (all degreasing types)		517,000	16,580,000	3.12

Note.—Blanks indicate data not available.

Affected Population

A measure of the population which is exposed to a high contaminant concentration due to the individual type degreasing operations can be obtained as follows: the values of x for which

$$\frac{\overline{\chi}(x)}{F} = m \qquad (4)$$

where m = 0.1 and 1.0 are determined by iteration. The value of $\overline{\chi}(x)$, the annual mean ground level concentration, is computed from the equation (76)

$$\overline{\chi}(x) = \frac{2.03\ Q_m}{\sigma_z \overline{u} x} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \qquad (5)$$

where Q_m = emission rate, g/s
H = effective emission height, m
x = downwind distance from source, m
$\overline{u}$ = average wind speed, 4.5 m/s
σ_z = vertical dispersion coefficient, m

For atmospheric stability Class C (neutral conditions), σ_z is given by (79)

$$\sigma_z = 0.113(x^{0.911}) \qquad (6)$$

The affected area, A(km^2), is then computed as

$$A = (x_2{}^2 - x_1{}^2) \qquad (7)$$

where x_1 and x_2 are the roots of Equation 4 for a given value of m.

The state degreasing capacity-weighted mean population density, $\overline{D}_P$, is calculated as follows:

$$\overline{D}_P = \frac{\sum_i C_i\ D_{P_i}}{\sum_i C_i}, \text{ persons/km}^2 \qquad (8)$$

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(79) Eimutis, E. C., and M. G. Konicek. Derivations of Continuous Functions for the Lateral and Vertical Atmospheric Dispersion Coefficients. Atmospheric Environment, 6(11): 859-863, 1972.

where C_i = number of degreasers (each type) of state i
Dp_i = state population density for state i

The product $(A)\overline{D}p$ is designated the "affected population." The affected population was computed for each solvent and each degreasing operation type for which the source severity for the representative source exceeds 0.1 and 1.0. This was done for a hazard factor based on both the AAQS and the TLV. The results are presented in Table 33. In addition, the mean population densities (from Equation 8) for each type of degreassing operation are presented. A sample calculation for the state degreasing is presented in Appendix C.

TABLE 33. POPULATION EXPOSED TO SOURCE SEVERITIES GREATER THAN 0.1 AND 1.0 DUE TO EMISSIONS FROM REPRESENTATIVE DEGREASING OPERATIONS

		Number of persons			
		Where $\bar{X}/F \geq 1.0$		Where $\bar{X}/F \geq 0.1$	
Degreaser type/Solvent	Population density, persons/km^2	F based on AAQS	F based on TLV	F based on AAQS	F based on TLV
Cold cleaning:					
Butanol	88.8	0	0	0	0
Acetone	88.8	0	0	0	0
Methyl ethyl ketone	88.8	0	0	0	0
Hexane	88.8	0	0	0	0
Naptha	88.8	0	0	0	0
Mineral spirits	88.8	0	0	0	0
Toluene	88.8	0	0	0	0
Xylene	88.8	0	0	0	0
Cyclohexane	88.8	0	0	0	0
Benzene	88.8	0	0	0	0
Ether	88.8	0	0	0	0
Carbon Tetrachloride	88.8	0	0	0	0
Fluorobarbons	88.8	0	0	0	0
Methylene chloride	88.8	0	0	0	0
Perchloroethylene	88.8	0	0	0	0
Trichloroethylene	88.8	0	0	0	0
1,1,1-Trichloroethane	88.8	0	0	0	0
Open top vapor degreasing					
Fluorocarbons	94.6	0	0	12	0
Methylene chloride	94.6	0	0	92	0
Perchloroethylene	94.6	0	0	35	0
Trichloroethylene	94.6	0	0	56	0
1,1,1-Trichloroethane	94.6	0	0	22	0
Conveyorized vapor degreasing					
Fluorocarbons	95.7	0	0	45	0
Methylene chloride	95.7	18	0	273	9
Perchloroethylene	95.7	4	0	109	0
Trichloroethylene	95.7	0	0	74	0
1,1,1-Trichloroethane	95.7	0	0	143	0
Fabric scouring					
Benzene	114.3	0	5	76	128
Xylene	114.3	0	0	76	0
Perchloroethylene	114.3	0	0	62	0
Trichloroethylene	114.3	0	0	60	0

SECTION 5

CONTROL TECHNOLOGY

CONTROLS TO RETARD SOLVENT BATH EMISSIONS

Five devices can reduce emissions from the solvent bath:

- Improved cover
- High freeboard
- Refrigerated chillers
- Carbon adsorption
- Safety switches

Improved Cover

The cover is the single most important control device for open top vapor degreasers. Although covers are normally provided on open top degreasers as standard equipment, the cover may be simplified so that it will be more frequently used if it is either mechanically assisted, powered, or automated.

For vapor degreasers, covers should open and close in horizontal motion, so that air/vapor interface is not disturbed. Such covers include roll-type plastic covers, canvas curtains, or guillotine covers. Automating covers on large open top vapor degreasers is advantageous. Covers may be powered pneumatically or electrically and are usually manually controlled with an automatic cutoff. The most advanced covering systems are automated in coordination with the hoist or conveyor. Covers can be designed so they close while parts are cooking and drying; thus covers would be opened for only a short time while parts are actually entering or exiting the degreaser.

On cold cleaners, covers are frequently assisted by means of spring loading or counterweighing. A foot-operated pedal or powered system can facilitate cover efficiency. Two additional types of covers may be used: the submerged cover and a water cover. The submerged cover (commercially termed "turbulence baffle") is a horizontal sheet of material submerged about 50 mm below the entire surface of the liquid solvent in a cold cleaner that is vigorously pump agitated. The water cover is simply a layer of water about 50 mm to 100 mm thick over a halogenated solvent. The water cover cannot be used in applications where water would corrode the metal surface or cause chemical degradation of the halogenated solvent.

Even though conveyorized degreasers include covers in their design, additional cover-related controls can be used. These include 1) minimizing openings and 2) covering openings during shutdown hours. The American Society of Testing and Materials (ASTM) has recommended that there be no more than 150 mm clearance between parts on the conveyor and sides of the opening (80). This clearance is termed the average silhouette clearance and is defined as the average distance between the side at the opening and the part being cleaned.

Covers can be made for the entrance and exit of the conveyorized degreaser so that they can be closed after degreaser shutdown. The cover (i.e., "downtime cover") can be any material that impedes drafts into the degreaser and should cover 80% to 90% of the opening. This shutdown cover is most important during the hours immediately after shutdown because the hot solvent is cooling by evaporation. Even after the solvent sump has cooled, the downtime cover will be effective for the more volatile vapor degreasing solvents.

A cover on an open top vapor degreaser has been shown to reduce total emissions by 20% to 40%; effectiveness varies depending upon the frequency of cover use (80).

Establishing a single control efficiency for a cold cleaning cover is not possible because emission reduction varies too greatly with respect to solvent volatility, draft velocity, freeboard ratio, operating temperature and agitation. However, bath evaporation rate does vary directly with solvent volatility at normal operating temperature. Although a closed cover can eliminate bath evaporation, the cover can do nothing to reduce carryout. Thus a normally closed cover becomes an effective control device only when bath evaporation accounts for the major portion of total emissions. More specifically, when solvent volatility is moderate to high (approximately 2.1 kPa at 38°C), closing the cover at all times is an effective control technique when parts are not being cleaned manually in the cold cleaner. The cover should always be closed when the bath is agitated or heated. If none of these conditions apply, the cover should at least be closed during long periods of disuse, such as shutdown hours and idle periods greater than 0.5 hr (80).

For conveyorized degreasers, an estimated 18% of total emissions are due to evaporation during downtime (80). Most of this loss can be eliminated by a downtime cover.

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(80) Control of Volatile Organic Emissions from Organic Solvent Metal Cleaning Operations (draft document). U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1977. pp. 3-1 to 3-26.

High Freeboard

The freeboard serves primarily to reduce drafts near the air/solvent interface. An acceptable freeboard height is determined by its freeboard ratio. Although the conventional freeboard ratio, which is defined as the freeboard height divided by the width (not length) of the degreaser's air/solvent area, is simple and convenient, it does not consider the length of the working area. Instead of using just the degreaser's width to define the ratio, including the degreaser's length can be more accurate because it effects the freeboard height needed to achieve optimum control. One proposed definition of a modified freeboard ratio is the freeboard height divided by the square root of the product of the width and length of the degreaser's area.[a]

Normally, the conventional freeboard ratio is 0.5 to 0.6 for open top vapor degreasers, but if more volatile solvents are used, namely methylene chloride or fluorocarbon solvents, the minimum freeboard ratio is 0.75 (80). The ASTM has recommended (ASTM D-26) that a minimum freeboard ratio of 0.75 be an alternative control for open top degreasers (80).

For degreasers that have a length much greater than their width, the "modified freeboard ratio" would require an appreciably higher freeboard height than would an equal conventional freeboard ratio.

For an idling open top vapor degreaser (has no work load), emission reduction resulting from raising a conventional freeboard ratio from 0.5 to 0.75 may typically be 25% to 30% (80, 81). An increase in the ratio from 0.5 to 1.0 may yield a 50% reduction in emissions (80, 81). For open top vapor degreasers with normal work loads, total emission reduction will be less than that given above because the freeboard is less effective in reducing carryout emissions than solvent bath emissions.

Freeboard height has little effect on cold cleaning solvents with low volatilities, such as mineral spirits. An increase of freeboard ratio above typical values (e.g., 0.5) yields a benefit

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[a] Letting $\overline{F}$ equal freeboard height, W equal width of degreaser's opening and L equal length of the opening, then the conventional freeboard ratio equals $\overline{F}/W$, and the modified freeboard ratio equals $\overline{F}/(W \text{ x } L)^{\frac{1}{2}}$

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(81) Suprenant, K. S. Study of the Emission Control Effectiveness of Increased Freeboard on Open Top Degreasers. In: Study to Support New Source Performance Standards for Solvent Metal Cleaning Operations, Appendix Reports, D. W. Richards and K. S. Suprenant, eds. Contract 68-02-1329, Task 9, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 20, 1976. Appendix C-12.

only for cold cleaners with high volatility solvents, such as halogenated ones. Nevertheless, the Occupational Safety and Health Administration (OSHA) requires at least a 150-mm freeboard (80).

Refrigerated Chillers

Refrigerated chillers are emission control devices used on vapor degreasers. The vapors created within a vapor degreaser are prevented from overflowing out of the equipment by means of condenser coils and a freeboard water jacket. Refrigerated freeboard chillers are an addition to this basic system. In appearance, they seem to be a second set of condenser coils located slightly above the primary condenser coils of the degreaser (Figure 25) (82). Functionally, however, they achieve a different purpose. Primary condenser coils control the upper limit of the vapor zone, while refrigerated freeboard chilling coils impede diffusion of solvent vapors from the vapor zone into the work

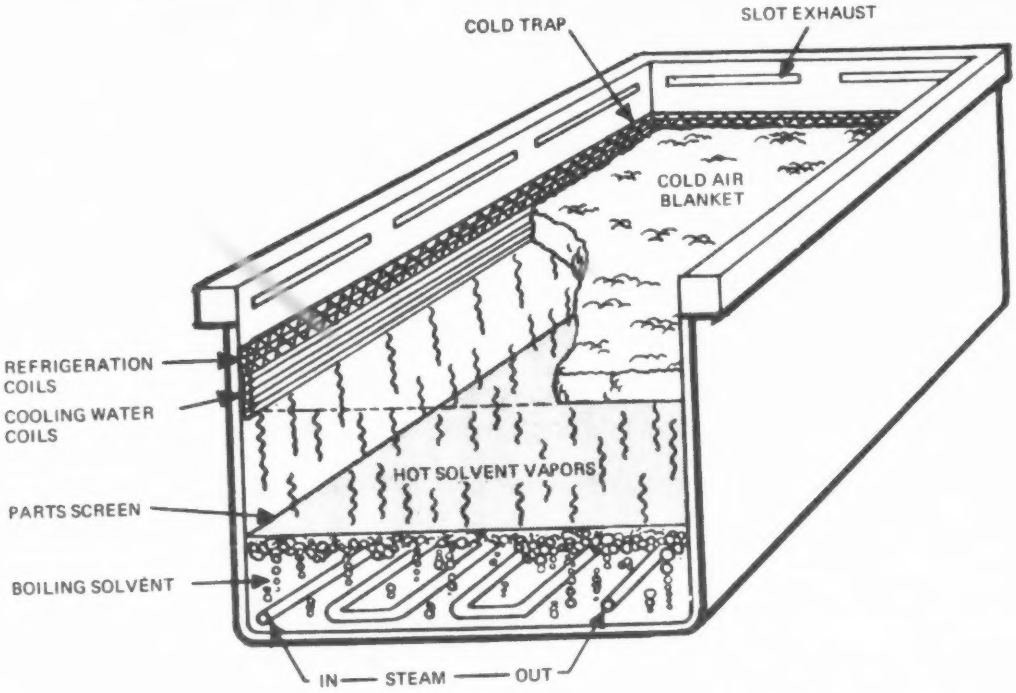
COLD TRAP
SLOT EXHAUST
COLD AIR BLANKET
REFRIGERATION COILS
COOLING WATER COILS
HOT SOLVENT VAPORS
PARTS SCREEN
BOILING SOLVENT
IN — STEAM — OUT

Figure 25. Schematic representation of degreaser with cold trap installed (82).

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(82) Chemical Engineers' Handbook, Fifth Edition. J. H. Perry and C. H. Chilton, eds. McGraw-Hill Book Co., New York, New York, 1973.

atmosphere. This is accomplished by chilling the air immediately above the vapor zone and creating a cold air blanket. This blanket also reduces mixing of air and solvent vapors by narrowing the air/vapor mixing zone, which results from a sharper temperature gradient. In addition, chilling decreases the upward convection of warm, solvent-laden air.

Patent coverage of this emission control method (the "cold trap") is limited to designs that control the refrigerant temperature at 0°C or colder (80). Manufacturers operating within this patent recommend a heat exchange temperature of -23°C to -30°C. Commercial systems operating between 1°C to 5°C are also available. Most major manufacturers of vapor degreasing equipment offer both types of refrigerated freeboard chillers.

These systems are designed with a timed defrost cycle to remove ice from the coils and to restore heat exchange efficiency. Although liquid water formed during the defrost cycle is directed to the water separator, water contamination of the degreasing solvent is not uncommon.

Refrigerated freeboard chillers are normally qualified by specifying cooling capacity per length of perimeter. The above-freezing refrigerated freeboard chiller is frequently designed to have a minimum of 865 W/m-k cooling capacity per 305 mm of air/vapor interface perimeter. The below-freezing refrigerated freeboard chiller (i.e., "cold trap") is reported to be normally designed along the following specifications (80):

Degreaser width, m	Minimum cooling capacity, W/m-k
<1.1	346
>1.1	519
>1.8	692
>2.4	865
>3.0	1,038

Normally, each pass of finned cooling coil is expected to remove 173 W/m-k (80).

A third type of refrigerated chiller is the refrigerated condenser coil. Rather than provide an extra set of chilling coils as the freeboard chillers do, refrigerated condenser coils replace primary condenser coils. If coolant in the condenser coils is sufficiently refrigerated, it will create a layer of cold air above the air/vapor interface. Du Pont and Rucker Ultrasonics have recommended that the cooling rate of refrigerated condenser coils be equal to 100% to 120% of the heat input rate in the boiling sump in order to give optimum emission control (80). Refrigerated condenser coils are normally used only on small open top vapor degreasers (especially with fluorocarbon solvent) because energy consumption may be too great for larger open top vapor degreasers. The refrigerated condenser coil offers portability of the open top degreaser by excluding the need for plumbing to cool condenser coils with tap water.

The refrigerated chiller will reduce emissions by approximately 40%. Data are available for below-freezing refrigerated freeboard chillers but not for above-freezing chillers or refrigerated condensing coils. Three tests on cold traps measured emission reductions of 28% to 62% (79, 83, 84). The vendor guarantees at least 40% emission reduction for the cold trap, although one test measured a reduction of only 16% (79, 85). However, this particular chiller was installed in 1968, so the design was judged to be nonrepresentative of present designs.

No tests have been performed for chillers on cold cleaners. A chiller on a cold cleaner could have the same effectiveness on a normally closed cover, though it will cost considerably more.

Carbon Adsorption

Carbon adsorption is used frequently to capture solvent emissions from metal cleaning operations. Adsorption is the process of removing molecules from a stream by contacting them with a solid. Gases, liquids, or solids can be selectively removed from air streams with materials known as adsorbents. The material which adheres to the adsorbent is called the adsorbate.

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(83) Suprenant, K. S. Evaluation of Two Refrigerated Freeboard Chillers. In: Study of Support New Source Performance Standards for Solvent Metal Cleaning Operations, Appendix Reports, D. W. Richards and K. S. Suprenant, eds. Contract 68-02-1329, Task 9, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 30, 1976. Appendix C-3.

(84) Bollinger, J. C. Evaluation of Refrigerated Freeboard Chillers. In: Study to Support New Source Performance Standards for Solvent Metal Cleaning Operations, Appendix Report, D. W. Richards and K. S. Suprenant, eds. Contract 68-02-1329, Task 9, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 30, 1976. Appendix C-7.

(85) Suprenant, K. S. Evaluation of (1) A Pneumatic Cover (2) Refrigeration. In: Study to Support New Source Performance Standards for Solvent Metal Cleaning Operations, Appendix Reports, D. W. Richards and K. S. Suprenant, eds. Contract 68-02-1329, Task 9, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 30, 1976. Appendix C-5.

The mechanism by which components are adsorbed is complex, and although adsorption occurs at all solid interfaces, it is minimal unless the adsorbent has a large surface area, is porous, and possesses capillaries. The important characteristics of solid adsorbents are their large surface-to-volume ratios and preferential affinity for individual components.

The adsorption process includes three steps. The adsorbent is first contacted with fluid, and a separation by adsorption results. Second, the unadsorbed portion of fluid is separated from the adsorbent. For gases this operation is completed when gases leave the adsorbent bed. Third, the adsorbent is regenerated by removing adsorbate from the adsorbent. For solvent recovery, low pressure steam is used to regenerate the adsorbent and the condensed vapors are separated from the water by decantation, distillation, or both.

Activated carbon is capable of adsorbing 95% to 98% of many organic vapors from air at ambient temperature in the presence of water in the gas stream (40). Because adsorbed compounds have low vapor pressure at ambient temperatures, recovery of solvents present in air in small concentrations is low.

When a mixture of solvent vapor in air is passed over activated carbon, removal of solvent vapor is complete at the beginning, but as the adsorptive capacity of the activated carbon is approached, traces of vapor appear in the exit air. This situation is known as breakthrough. As the air flow is continued, although additional amounts of solvent are adsorbed, the concentration of solvent vapor in the exit air increases until it equals that in the inlet air. The adsorbent is saturated under these conditions.

Adsorption of a mixture of organic vapors in air is not uniform, the more easily adsorbed constituents being those with higher boiling points. When air containing a mixture of organic vapors is passed over activated carbon, vapors are equally adsorbed at the start. However, as the amount of the higher boiling constituent in the adsorbent increases, the more volatile constituent revaporizes. Thus the exit vapor consists primarily of the more volatile constituent after breakthrough has been reached. This process continues for each organic constituent until the highest boiling constituent is present in the exit gas. To control organic vapor mixtures, the adsorption cycle should be stopped when the first breakthrough occurs as determined by detection of vapors in the exit gas. Many theories have been advanced to explain the selective adsorption of certain vapors or gases. These theories are discussed by Perry and Chilton (45) and will not be repeated here.

The quantity of organic vapors adsorbed by activated carbon is a function of the particular vapor in question, the adsorbent, the adsorbent temperature, and the vapor concentration. Removal of gaseous vapors by physical adsorption is practical for gases with a molecular weight over 45 (45). Each type of activated carbon has its own adsorbent properties for a given vapor, and the quantity of vapor adsorbed for a particular vapor concentration in the gas and at a particular temperature is best determined experimentally. The quantity of vapor adsorbed increases when vapor concentration increases and adsorbent temperature decreases.

After breakthrough has occurred, the adsorbent is regenerated by heating until the adsorbate has been removed. A carrier gas is required to sweep out vapors released. Low pressure saturated steam is used for activated carbon as both the heat source and carrier gas. Superheated steam (343°C) may be necessary to remove high boiling compounds and return the carbon to its original condition when the accumulation of high boiling compounds has reduced carbon capacity to the point where complete regeneration is necessary.

Steam requirements for regeneration are a function of external heat losses and the nature of the solvent. The amount of steam adsorbed per kilogram of solvent, as a function of elapsed time, passes through a minimum. The carbon should be regenerated for this length of time to permit the minimum use of steam (45). After regeneration, the carbon bed is hot (approximately 200°C) and watersaturated. It is cooled and dryed by blowing solvent-free air through the bed. Water evaporation aids carbon cooling. If high temperature (greater than 300°C) steam is used, other means of cooling are required.

Fixed-bed adsorbers arrayed in two or more parallel bed arrangements are used to remove solvent vapors from air. These are batch arrangements, where a bed is used until breakthrough occurs and then regenerates. The simplest adsorber design of this type is a two-bed system where one carbon bed is regenerating as the other is adsorbing (see Figure 26) (41). A three-bed arrangement permits a greater quantity of solvent to be adsorbed per unit of carbon because effluent passes through two beds in series while the third bed regenerates. This permits activated carbon to be used after breakthrough since the second bed in the series removes solvent vapors from the first bed exit gas. When the first bed is saturated, it is removed from the stream for regeneration; the bed which was used to remove final traces of solvent vapors from effluent becomes the new first bed; and the bed which was regenerated becomes the new second bed.

Heat released in the adsorption process causes the temperature of the adsorbent to increase. If the concentration of solvent vapors is not high, as in the case of degreasing operations, the temperature rise is typically 10°C (86).

The pressure drop through a carbon bed is a function of gas velocity, bed depth, and particle size. Activated carbon

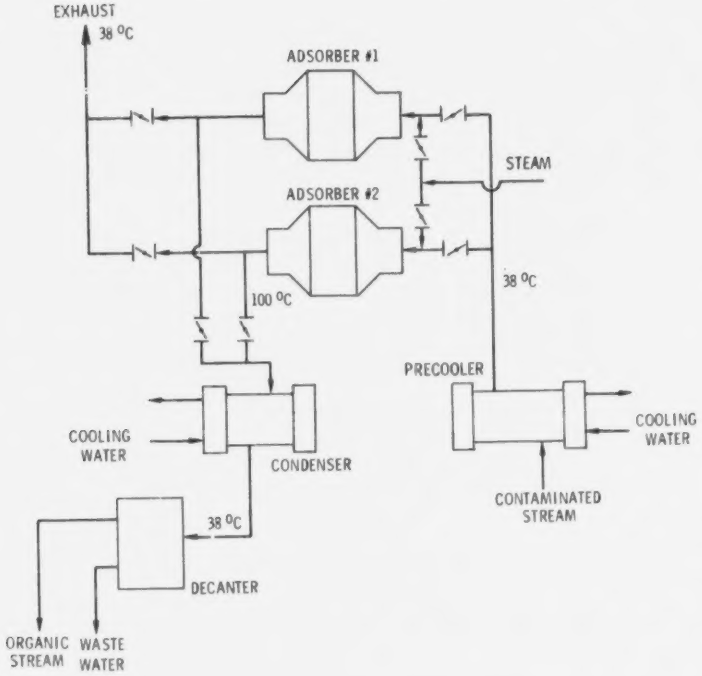
EXHAUST
38 °C
ADSORBER #1
STEAM
ADSORBER #2
38 °C
100 °C
PRECOOLER
COOLING WATER
CONDENSER
COOLING WATER
CONTAMINATED STREAM
38 °C
DECANTER
ORGANIC STREAM
WASTE WATER

Figure 26. Carbon adsorption system (41).

manufacturers supply empirical correlations for pressure drop in terms of these quantities as well as pressure drop resulting from directional change of the gas stream at inlet and outlet.

Control of solvent vapor emissions by adsorption on activated carbon is applied when adsorbate recovery is economically desirable.

Several aspects of using carbon adsorption with degreasers are distinctive. For example, solvent mixtures are sometimes used. Although combinations will be adsorbed, collected solvent vapors will be rich in the more volatile components so that recovered solvent is rarely identical in concentration to that used in the cleaning system. In addition, there are effluent components that are water soluble, such as acetone or butanol used as cosolvents with Fluorocarbon 113 and various stabilizers added to most solvents to inhibit decomposition. These water soluble components will be selectively extracted by the steam during the desorption process. In such cases, if the recovered solvent has not decomposed, it can be reused although fresh solvent, stabilizers, and/or cosolvents must be added.

Carbon adsorption systems for solvent metal cleaning can be expected to achieve only 40% to 65% reduction of the total solvent emission. This is because the ventilation apparatus of the control system cannot capture all solvent vapors and deliver them to the adsorption bed. The major loss areas are dragout on parts, leaks, spills, and disposal of waste solvent. Improved ventilation design can increase an adsorber's overall emission control efficiency. Higher ventilation rate alone, however, will not necessarily be advantageous; it will require large, expensive adsorbers and may disrupt the air/vapor interface.

Tests performed on carbon adsorption systems controlling both an open top vapor degreaser and a conveyorized nonboiling degreaser measured 60% and 65% emission reduction, respectively (80, 87, 88). Many adsorption systems, however, yield less than 40% emission reduction because 1) the inlet collection efficiency is poor and 2) the carbon adsorber is improperly maintained or adjusted. The inlet collection efficiency is the percentage of solvent vapors from the degreaser that are captured by the inlet duct of the carbon adsorption system. Often less than one-half of the solvent emissions are captured by the carbon adsorption system.

Ventilation rates normally should be at least but not much greater than 0.25 m^3/s per square meter of air/vapor area (80). Preferably, the freeboard height should be enough to satisfy minimum freeboard ratios of 0.6 to 0.75. The cover should not close above the inlet vents (lip exhausts) when the adsorber is running, or excess solvent will be drawn into the adsorber.

Two tests have indicated poor inlet collection efficiency (85, 89). Measured emission reductions were 21% and 25%, respectively. Furthermore, one test showed an 8% emission increase,

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(87) Richards, D. W. Evaluation of Carbon Adsorption Recovery. In: Study to Support New Source Performance Standards for Solvent Metal Cleaning Operations, Appendix Reports, D. W. Richards and K. S. Surprenant, eds. Contract 68-02-1329, Task 9, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 30, 1976. Appendix C-10.

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most likely because freeboard height was extremely short (0.05 to 0.10) and because breakthrough occurred frequently (90).

Safety Switches

Safety switches are preventive devices used only for vapor degreasers. They reduce emissions only during malfunctions, not during normal operation. The five main types of safety switches are 1) safety vapor thermostat, 2) condenser water flow switch and thermostat, 3) sump thermostat, 4) solvent level control, and 5) spray safety switch. Switches one through four turn off the sump heat, and switch five turns off the spray.

The safety vapor thermostat is the most important switch, which detects the solvent vapor zone when it rises above the condenser coils. When hot vapors are sensed, heat is turned off. The safety thermostats should be the manual reset type and should be checked frequently for operation. By preventing the vapor level from rising above the condenser coils and causing emissions, the safety vapor thermostat reduces emissions and protects the operator's health. OSHA already requires that open top degreasers have a safety vapor thermostat.

The condenser water flow switch and thermostat turn off the sump heat when the condenser water stops circulating or becomes warmer than specified. If the condenser water flow switch and thermostat are properly adjusted, they will serve as a backup for the safety vapor thermostat and also assure efficient operation of the condenser coils.

Both the boiling sump thermostat and solvent level control prevent the sump from overheating and causing solvent decomposition. The boiling sump thermostat cuts off the sump heat when the sump temperature rises above the solvent's boiling point. This is caused by excessive oil concentration. The solvent level control turns off the heat when the level of the boiling sump drops down to the height of the sump heater coils (80). Without this control, heat can break down the solvent. Occasionally it will undergo an exothermic reaction, emitting noxious fumes, such as hydrochloric acid, which cause extensive corrosion.

The spray safety switch is not installed as often as other safety switches. If the vapor level drops below a specified level, then the pump for the spray will be cut off until the normal vapor level returns. Thus the spray safety switch prevents the operator from spraying above the vapor level and causing emissions (80).

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The effectiveness of the five safety switches in reducing emissions cannot be estimated because their operation results from poor degreasing maintenance and use.

Incineration

Incineration conceptually could be used to control emissions from degreasing. It could be applied to systems using petroleum hydrocarbons and oxygenated solvents which readily combust to carbon dioxide and water. Although chlorinated hydrocarbons are nonflammable under normal conditions, they can be pyrolyzed at temperatures in the incineration range. This pyrolytic decomposition will release chlorine, hydrochloric acid, and phosgene, depending on decomposition conditions. These products would have to be removed from the off-gas stream of the incinerator before exhausting to the atmosphere, and this would require sophisticated gas cleaning equipment.

Liquid Absorption

Liquid absorption has been investigated for use in solvent metal cleaning. For example, trichloroethylene vapors in air can be reduced by absorption in mineral oil. However, at an absorption column temperature of 30°C, the air stream leaving the column can contain about 120 ppm mineral oil. Thus this process can result in controlling one hydrocarbon but emitting another at an equal or greater rate (80). It appears that except for recovery of 1) high concentrations of solvent vapor in air, 2) very valuable vapors or, 3) highly toxic chemical vapors, this method of emission control is impractical (80).

CONTROLS TO MINIMIZE CARRYOUT

The main control device for carryout emissions from cold cleaners is a simple drainage facility. Two types of drainage facilities are the external and internal drainage racks (or shelves). The external drainage rack is attached to the top side of the cold cleaner. The liquid solvent on the cleaned parts drains onto the drainage shelf and flows back into the cold cleaning bath.

An internal drainage facility is located beneath the cover. It may be a basket holding parts that is suspended over the solvent bath or a shelf from which the solvent drains.

The main control devices for carryout emissions from conveyorized degreasers are a drying tunnel and rotating baskets. A drying tunnel is an extention of sheet metal from the exit of the conveyorized degreaser. This tunnel extension gives cleaned parts more time to dry completely. The drying tunnel will work well in combination with carbon adsorption. Rotating baskets may be used on cross-rod degreasers and Ferris wheel degreasers. The rotating basket is a perforated cylinder containing parts to be cleaned that is slowly rotated through the cleaning system so that the parts cannot trap liquid solvent.

The effectiveness of these control devices cannot be quantified. The amount of carryout depends upon the various types of work load (amount of crevices) and the quality of operation. In addition no information is available on the extent to which any of the control measures discussed are being utilized in plants practicing degreasing.

SECTION 6

GROWTH AND NATURE OF THE INDUSTRY

PRESENT TECHNOLOGY

Current technology for degreasing operations (both degreasers and fabric scourers) is discussed in Section 3 of this report.

EMERGING TECHNOLOGY

Technology for degreasing processes is presently static. Recent patent literature reveals no new processes for either degreasers or fabric scourers (91).

INDUSTRY PRODUCTION TRENDS

Degreasers

The overall metals cleaning industry is growing at a rate of 3% to 5%/yr (39). However, metal cleaning is closely connected to the overall economy. Production cutbacks in basic industries, particularly in automotive-related industries, could reduce the overall growth rate.

Distribution of solvent usage may also change in the next several years, depending upon air pollution regulations. In 1972, the 32 states listed in Table 34 had no restrictions on the use of trichloroethylene. Los Angeles Rule 66 restricts the use of trichloroethylene but exempts perchloroethylene and 1,1,1-trichloroethane from controls. Therefore, in states with Rule 66-type legislation, the trend has been to restrict solvents rather than require installation of equipment. Thus if more states adopt Rule 66-type legislation, the consumption of trichloroethylene will further decline. The trend in solvent usage is thus dependent upon legislation (16).

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TABLE 34. STATES WITHOUT RESTRICTIONS ON TRICHLOROETHYLENE USAGE (1972) (16)

Alabama
Alaska
Arkansas
Delaware
Florida
Georgia
Hawaii
Idaho
Illinois[a]
Iowa
Kansas
Maine
Maryland[b]
Michigan
Minnesota
Mississippi
Missouri
Montana
Nebraska
Nevada
New Hampshire
New Mexico
North Dakota
Oregon
South Carolina
South Dakota
Utah
Vermont
Washington
West Virginia
Wisconsin
Wyoming

[a] Illinois APC Board installation permit required if exhausted.

[b] Stack exhaust permit required.

Fabric Scourers

As a whole, the textile industry has been growing at an annual 4% to 5% rate since 1970 (92). The fabric scouring industry can thus be assumed to be growing at the same rate.

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APPENDIX A

DERIVATIONS OF SOURCE SEVERITY EQUATIONS[a]

SUMMARY OF MAXIMUM SEVERITY EQUATIONS

The maximum severity of pollutants may be calculated using the mass emission rate, Q, the height of the emissions, H, and the ambient air quality standard or modified TLV. The equations summarized in Table A-1 are developed in detail in this appendix.

TABLE A-1. POLLUTANT SEVERITY EQUATIONS FOR ELEVATED SOURCES

Pollutant	Severity equation
Hydrocarbons	$S = \frac{162\ Q}{H^2}$
Others	$S = \frac{5.5\ Q}{TLV\ H^2}$

DERIVATION OF χ_{max} FOR USE WITH U.S. AVERAGE CONDITIONS

The most widely accepted formula for predicting downwind ground level concentrations from a point source is (76)

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \left\{ \left[\exp - \frac{1}{2} \left(\frac{y}{\sigma_y} \right)^2 \right] \left[\exp - \frac{1}{2} \left(\frac{H}{\sigma_z} \right)^2 \right] \right\} \qquad \text{(A-1)}$$

where χ = downwind ground level concentration at reference coordinate x and y with emission height of H, g/m^3

Q = mass emission rate, g/s

σ_y = standard deviation of horizontal dispersion, m

σ_z = standard deviation of vertical dispersion, m

u = wind speed, m/s

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[a] This appendix was prepared by T. R. Blackwood and E. C. Eimutis of Monsanto Research Corporation, Dayton, Ohio.

y = horizontal distance from centerline of dispersion, m

H = height of emission release, m

x = downwind emission dispersion distance from source of emission release, m

π = 3.1416

We assume that χ_{max} occurs when x is much greater than 0 and when y equals 0. For a given stability class, standard deviations of horizontal and vertical dispersion have often been expressed as functions of downwind distance by power law relationships as follows (93):

$$\sigma_y = ax^b \qquad \text{(A-2)}$$

$$\sigma_z = cx^d + f \qquad \text{(A-3)}$$

Values for a, b, c, d, and f are given in Tables A-2 (94) and A-3. Substituting these general equations into Equation A-1 yields

$$\chi = \frac{Q}{ac\pi ux^{b+d} + a\pi ufx^b} \exp -\left[\frac{H^2}{2(cx^d + f)^2}\right] \qquad \text{(A-4)}$$

Assuming that χ_{max} occurs when x is less than 100 m or when the stability class is C, then f equals 0 and Equation A-4 becomes

$$\chi = \frac{Q}{ac\pi ux^{b+d}} \exp\left(\frac{-H^2}{2c^2x^{2d}}\right) \qquad \text{(A-5)}$$

For convenience, let

$$A_R = \frac{Q}{ac\pi u} \text{ and } B_R = \frac{-H^2}{2c^2}$$

so that Equation A-5 reduces to

$$\chi = A_R x^{-(b+d)} \exp\left(\frac{B_R}{x^{2d}}\right) \qquad \text{(A-6)}$$

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(93) Martin, D. O., and J. A. Tikvart. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. 61st Annual Meeting of the Air Pollution Control Association, St. Paul, Minnesota, June 23-27, 1968. 18 pp.

(94) Tadmor, J., and Y. Gur. Analytical Expressions for the Vertical and Lateral Dispersion Coefficients in Atmospheric Diffusion. Atmospheric Environment, 3(6):688-689, 1969.

TABLE A-2. VALUES OF a FOR THE COMPUTATION OF σ_y[a] (94)

Stability class	a
A	0.3658
B	0.2751
C	0.2089
D	0.1471
E	0.1046
F	0.0722

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[a] For Equation A-2: $\sigma_y = ax^b$

where x = downwind distance
b = 0.9031 (from Reference 94)

TABLE A-3. VALUES OF CONSTANTS USED TO ESTIMATE VERTICAL DISPERSION[a] (93)

Usable range, m	Stability class	Coefficient		
		c_1	d_1	f_1
>1,000	A	0.00024	2.094	9.6
	B	0.055	1.098	2.0
	C	0.113	0.911	0.0
	D	1.26	0.516	-13
	E	6.73	0.305	-34
	F	18.05	0.18	-48.6
		c_2	d_2	f_2
100 to 1,000	A	0.0015	1.941	9.27
	B	0.028	1.149	3.3
	C	0.113	0.911	0.0
	D	0.222	0.725	-1.7
	E	0.211	0.678	-1.3
	F	0.086	0.74	-0.35
		c_3	d_3	f_3
<100	A	0.192	0.936	0
	B	0.156	0.922	0
	C	0.116	0.905	0
	D	0.079	0.881	0
	E	0.063	0.871	0
	F	0.053	0.814	0

---

[a] For Equation A-3: $\sigma_z = cx^d + f$

Taking the first derivative of Equation A-6,

$$\frac{d\chi}{dx} = A_R \left\{ x^{-b-d}\left[\exp\left(B_R x^{-2d}\right)\right]\left(-\ 2\ dB_R x^{-2d-1}\right) + \exp\left(B_R x^{-2d}\right)(-\ b\ -\ d)x^{-b-d-1}\right\} \qquad \text{(A-7)}$$

and setting this equal to 0 (to determine the roots which give the minimum and maximum conditions of χ with respect to x) yields

$$\frac{d\chi}{dx} = 0 = A_R x^{-b-d-1}\left[\exp\left(B_R x^{-2d}\right)\right]\left(-\ 2\ dB_R x^{-2d}\ -\ b\ -\ d\right) \qquad \text{(A-8)}$$

Since we define that x is not equal to 0 or infinity at χ_{max}, the following expression must be equal to 0:

$$-\ 2\ dB_R x^{-2d}\ -\ d\ -\ b = 0 \qquad \text{(A-9)}$$

or

$$(b + d)x^{2d} = -\ 2\ dB_R \qquad \text{(A-10)}$$

or

$$x^{2d} = \frac{-\ 2\ dB_R}{b + d} = \frac{2\ dH^2}{2\ c^2(b + d)} = \frac{dH^2}{c^2(b + d)} \qquad \text{(A-11)}$$

or

$$x^{2d} = \frac{dH^2}{c^2(b + d)} \qquad \text{(A-12)}$$

Hence

$$x = \left[\frac{dH^2}{c^2(b + d)}\right]^{1/2d} \text{ at } \chi_{max} \qquad \text{(A-13)}$$

Thus Equations A-2 and A-3 (at f equals 0) become

$$\sigma_y = a\left[\frac{dH^2}{c^2(d + b)}\right]^{b/2d} \qquad \text{(A-14)}$$

$$\sigma_z = c\left[\frac{dH^2}{c^2(b + d)}\right]^{d/2d} = \left(\frac{dH^2}{b + d}\right)^{1/2} \qquad \text{(A-15)}$$

The maximum will be determined for U.S. average conditions of stability. According to Gifford (95), this is when σ_y equals σ_z. Since b equals 0.9031, and upon inspection of Table A-2 under U.S. average conditions, σ_y equals σ_z, it can be seen that 0.881 is less than or equal to d, which is less than or equal to 0.905 (Class C stability[a]). Thus, it can be assumed that b is nearly equal to d in Equations A-14 and A-15 or

$$\sigma_z = \frac{H}{\sqrt{2}} \tag{A-16}$$

and

$$\sigma_y = \frac{ah}{c\sqrt{2}} \tag{A-17}$$

Under U.S. average conditions, σ_y equals σ_z and a is approximately equal to c if b is approximately equal to d and if f equals 0 (between Classes C and D, but closer to belonging in Class C).

Then

$$\sigma_y = \frac{H}{\sqrt{2}} \tag{A-18}$$

Substituting for σ_y from Equation A-18 and for σ_z from Equation A-16 into Equation A-1 and letting y equal 0,

$$\chi_{max} = \frac{2\ Q}{\pi u H^2}\ \exp\left[-\ \frac{1}{2}\left(\frac{H\sqrt{2}}{H}\right)^2\right] \tag{A-19}$$

or

$$\chi_{max} = \frac{2\ Q}{\pi e u H^2} \tag{A-20}$$

For U.S. average conditions, u equals 4.47 m/s so that Equation A-20 reduces to

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[a] The values given in Table A-3 are mean values for stability class. Class C stability describes these coefficients and exponents, only within about a factor of two (76).

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(95) Gifford, F. A., Jr. An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere. In: Meteorology and Atomic Energy 1968, Chapter 3. Slade, D. A., ed. Publication No. TID-24190, U.S. Atomic Energy Commission Technical Information Center, Oak Ridge, Tennessee, July 1968. p. 113.

$$\chi_{max} = \frac{0.0524\ Q}{H^2} \qquad \text{(A-21)}$$

DEVELOPMENT OF SOURCE SEVERITY EQUATIONS

The general source severity, S, relationship has been defined as follows:

$$S = \frac{\overline{\chi}_{max}}{F} \qquad \text{(A-22)}$$

where $\overline{\chi}_{max}$ = time-averaged maximum ground level concentration

F = hazard factor defined as the ambient air quality standard for criteria pollutants and a modified TLV [i.e., (TLV) (8/24) (1/100)] for noncriteria pollutants

Noncriteria Emissions

The value of $\overline{\chi}_{max}$ may be derived from χ_{max}, an undefined "short-term" (t_o) concentration. An approximation for longer term (t) concentration may be made as follows (76):

For a 24-hr time period,

$$\overline{\chi}_{max} = \chi_{max}\left(\frac{t_o}{t}\right)^{0.17} \qquad \text{(A-23)}$$

or

$$\overline{\chi}_{max} = \chi_{max}\left(\frac{3\ \text{min}}{1,440\ \text{min}}\right)^{0.17} \qquad \text{(A-24)}$$

or

$$\overline{\chi}_{max} = \chi_{max}\ (0.35) \qquad \text{(A-25)}$$

Since the hazard factor is defined and derived from TLV values as follows:

$$F = \text{TLV}\left(\frac{8}{24}\right)\left(\frac{1}{100}\right) \qquad \text{(A-26)}$$

$$F = 3.33 \times 10^{-3}\ \text{TLV} \qquad \text{(A-27)}$$

then the severity factor, S, is defined as

$$S = \frac{\overline{\chi}_{max}}{F} = \frac{0.35\ \chi_{max}}{3.33 \times 10^{-3}\ \text{TLV}} \qquad \text{(A-28)}$$

$$S = \frac{105\ \chi_{max}}{TLV} \qquad \text{(A-29)}$$

If a weekly averaging period is used, then

$$\bar{\chi}_{max} = \chi_{max}\left(\frac{3}{10{,}080}\right)^{0.17} \qquad \text{(A-30)}$$

or

$$\bar{\chi}_{max} = 0.25\ \chi_{max} \qquad \text{(A-31)}$$

and

$$F = TLV\left(\frac{40}{168}\right)\left(\frac{1}{100}\right) \qquad \text{(A-32)}$$

$$F = 2.38 \times 10^{-3}\ TLV \qquad \text{(A-33)}$$

and the severity factor, S, is

$$S = \frac{\bar{\chi}_{max}}{F} = \frac{0.25\ \chi_{max}}{2.38 \times 10^{-3}\ TLV} \qquad \text{(A-34)}$$

or

$$S = \frac{105\ \chi_{max}}{TLV} \qquad \text{(A-35)}$$

which is entirely consistent, since the TLV is being corrected for a different exposure period.

Therefore, the severity can be derived from χ_{max} directly without regard to averaging time for noncriteria emissions. Thus combining Equations A-35 and A-21, for elevated sources, gives

$$S = \frac{5.5\ Q}{TLV\ H^2} \qquad \text{(A-36)}$$

Hydrocarbon Severity

The primary standard for hydrocarbons is reported for a 3-hr averaging time.

$$t = 180\ \text{min}$$

$$\bar{\chi}_{max} = \chi_{max}\left(\frac{3}{180}\right)^{0.17} \qquad \text{(A-37)}$$

$$= 0.5\ \chi_{max} \qquad \text{(A-38)}$$

$$\overline{\chi}_{max} = \frac{(0.5)(0.052)Q}{H^2} \qquad \text{(A-39)}$$

$$\overline{\chi}_{max} = \frac{0.026\ Q}{H^2} \qquad \text{(A-40)}$$

For hydrocarbons, the concentration of 1.6×10^{-4} g/m^3 has been issued as a guideline for achieving oxidant standards (96). Therefore

$$S = \frac{\overline{\chi}_{max}}{F} = \frac{0.026\ Q}{1.6 \times 10^{-4}\ H^2} \qquad \text{(A-41)}$$

or

$$S = \frac{162.5\ Q}{H^2} \qquad \text{(A-42)}$$

AFFECTED POPULATION CALCULATION

Another form of the plume dispersion equation is needed to calculate the affected population since the population is assumed to be distributed uniformly around the source. If the wind directions are taken to 16 points and it is assumed that the wind directions within each sector are distributed randomly over a period of a month or a season, it can be assumed that the effluent is uniformly distributed in the horizontal within the sector. The appropriate equation for average concentration, $\overline{\chi}$, in grams per cubic meter is then (97)

$$\overline{\chi} = \frac{2.03\ Q}{\sigma_z u x} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \qquad \text{(A-43)}$$

To find the distance at which $\overline{\chi}/F$ equals 1.0, roots are determined for the following equation:

$$\frac{2.03\ Q}{F\sigma_z u x} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] = 1.0 \qquad \text{(A-44)}$$

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(96) Code of Federal Regulations, Title 42 - Public Health, Chapter IV - Environmental Protection Agency, Part 410 - National Primary and Secondary Ambient Air Quality Standards, April 28, 1971. 16 pp.

(97) Schwartz, W. A., et al. Engineering and Cost Study of Air Pollution Control for the Petrochemical Industry. Volume I: Carbon Black Manufacturing by the Furnace Process. EPA-450/3-73-006-a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 116 pp.

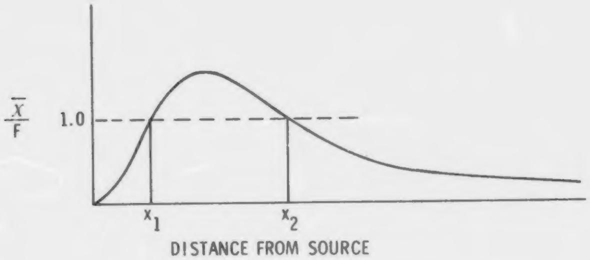
keeping in mind that

$$\sigma_z = cx^d + f$$

where c, d, and f are functions of atmospheric stability and are assumed to be selected for stability Class C.

Since Equation A-44 is a transcendental equation, the roots are found by an iterative technique using the computer.

For a specified emission from a typical source, $\overline{\chi}/F$ as a function of distance might look as follows:



The affected population is contained in the area

$$A = \pi(x_2{}^2 - x_1{}^2) \qquad \text{(A-45)}$$

If the affected population density is D_P, the total affected population, P', is

$$P' = D_P A \text{ (persons)} \qquad \text{(A-46)}$$

APPENDIX B

SAMPLE CALCULATION FOR A REPRESENTATIVE DEGREASING OPERATION

DEGREASING TYPE: OPEN TOP VAPOR DEGREASING;
SOLVENT TYPE: TRICHLOROETHYLENE

Total Consumption of Trichloroethylene in Open Top Vapor Degreasing

From Table 11 total consumption for all vapor degreasing equals 112.7×10^3 metric tons.

From personal communication with J. L. Shumaker, U.S. Environmental Protection Agency, the percent of vapor degreasing that is open top vapor degreasing is 73%. Therefore, total consumption of trichloroethylene in open top vapor degreasing is

$$(0.73)(112.7 \times 10^3) = 81.9 \times 10^3 \text{ metric tons}$$

Number of open top vapor degreasers using trichloroethylene

From Table 7 the total number of open top vapor degreasers utilizing trichloroethylene equals 11,440.

Average open top vapor degreaser solvent consumption

- Equals total consumption of trichloroethylene in open top vapor degreasing divided by number of degreasers using trichloroethylene.
- Equals 81.9×10^3 metric tons/yr divided by 11,440.
- Equals 7.165 metric tons/yr.
- Equals 7,165 kg/yr.

Average Stack Height of Open Top Vapor Degreasers Using Trichloroethylene

Using NEDS data in Appendix E for trichloroethylene, the average stack height equals 12.0 meters.

Average Frequency of Operation for Open Top Vapor Degreasers Using Trichloroethylene

Using NEDS data in Appendix E for trichloroethylene, the average frequency of operation is 78%.

Average Emission Factor for Open Top Vapor Degreasing

From Table 19 the emission factor is 775 g/kg of solvent consumed.

Average Emission Rate of Trichloroethylene from Open Top Vapor Degreasing

Average emission rate

- Equals average solvent consumption per year multiplied by average emission factor for open top degreasing divided by average frequency of operation divided by seconds per year.
- Equals 7,165 kg/yr multiplied by 775 g/kg divided by 0.78 divided by 3.154×10^7 s/yr.
- Equals 0.2257 g/s.

APPENDIX C

SAMPLE CALCULATIONS FOR THE STATE DEGREASING CAPACITY WEIGHTED POPULATION DENSITY

EXAMPLE: COLD CLEANING

State population densities are first determined by using state areas and state population data (1970 census).

A weighted density for each state is then determined by dividing the total number of cold cleaners in the specific state by the total number of degreasers in the United States and multiplying the quotient by the specific state population density.

Each weighted state population density is then added to determine the degreasing capacity weighted population density.

Table C-1 shows state population densities, state degreasing capacity-weighted densities, and total U.S.-weighted population density for cold cleaning.

TABLE C-1. WEIGHTED POPULATION DENSITY FOR COLD CLEANING OPERATIONS

State	Number of cold cleaning operations	State density, persons/km^2	Weighted population density, persons/km^2
Alabama	19,163	25.6	0.40
Alaska	1,245	0.19	0.0002
Arizona	10,003	5.94	0.05
Arkansas	11,302	13.94	0.13
California	130,575	48.6	6.2
Colorado	13,011	8.1	0.09
Connecticut	21,103	237.6	4.11
Delaware	2,600	105.8	0.225
District of Columbia	2,514	4,723	9.73
Florida	41,596	4.7	0.16
Georgia	28,439	29.8	0.69
Hawaii	3,137	44.98	0.115
Idaho	4,492	3.24	0.012
Illinois	68,485	75.87	4.26
Indiana	31,100	54.86	1.40
Iowa	16,416	19.23	0.26
Kansas	13,450	10.46	0.11
Kentucky	15,525	30.62	0.39
Louisiana	16,844	30.46	0.42
Maine	6,432	12.2	0.06
Maryland	16,844	151.23	2.09
Massachusetts	36,543	277.53	8.3
Michigan	56,597	59.65	2.77
Minnesota	22,690	18.34	0.34
Mississippi	11,412	17.61	0.16
Missouri	27,560	25.91	0.58
Montana	4,003	1.82	0.006
Nebraska	8,422	7.41	0.05
Nevada	2,771	1.7	0.004
New Hampshire	5,016	30.89	0.13
New Jersey	47,907	363.2	14.2
New Mexico	5,492	3.17	0.014
New York	113,743	145.02	13.5
North Carolina	32,210	39.19	1.03
North Dakota	2,880	3.4	0.008
Ohio	65,458	99.23	5.32
Oklahoma	14,561	13.98	0.17
Oregon	15,049	8.26	0.102
Pennsylvania	67,240	100.08	5.5
Rhode Island	8,837	339.54	2.46
South Carolina	14,769	32.55	0.39
South Dakota	2,185	3.36	0.006
Tennessee	22,959	35.83	0.67
Texas	66,557	16.14	0.88
Utah	6,322	4.98	0.026
Vermont	2,893	18.22	0.043
Virginia	21,677	44.01	0.78
Washington	20,298	19.42	0.32
West Virginia	8,324	27.3	0.19
Wisconsin	28,427	30.96	0.72
Wyoming	2,099	1.31	0.002
TOTAL	1,220,555		

APPENDIX D

STABILIZERS USED IN HALOGENATED HYDROCARBONS

TABLE D-1. STABILIZERS USED IN HALOGENATED HYDROCARBONS

Stabilizing compound	Solvent[a]	Typical solute concentration, wt %	Range of concentration, wt %	TLV, g/m^3	U.S. Patent number	Patent[b] issued to
Organic mercaptans and disulfides (Aonyl mercaptan, 2-mercaptoethyl methyl ether, *bis*(di-alkoxyphosphinothionyl) disulfide, *bis*(1-piperazinylthiocarbonyl) disulfide, cyclohexyl mercaptan, 2-mercaptoethanol, 2,3-dimercapto-1-propanol, dimethyl disulfide, di-*tert*-butyl disulfide, 4,4'-dithiodimorpholine, 2,2'-dithiobis(benzothiazole), dibenzyl disulfide, decamethylene dithiol, furfuryl Mercaptan)	MC	0.1			3,641,169	DOW
With butylene oxide		0.3			3,641,169	DOW
Diakyl sulfoxides (Glycidol(2,3-epoxy-1-propanol), dimethyl Sulfoxide, 3-(methylamino)propionitrile, 3-(dimethylamino)propionitrile, methylethanolamine, morpholine, acetonitrile, butylene oxide)	MC		0.05 to 6		3,535,392	PPG
1,3,5-Cycloheptatriene	PERC, TCENE	0.05			3,642,645	WCGG
1,3,5-Cycloheptatriene	PERC, TCENE	0.1			3,642,645	WCGG
With 1-(dimethylamino)propene-2		0.05			3,642,645	WCGG
Dipentene (terpene)	AER	0.5			3,352,789	ALL
Indene	AER	0.30		0.450	3,352,789	ALL
p-Mentha-1,5-diene	AER	0.30			3,352,789	ALL
α-Methylstyrene	AER	0.30			3,352,789	ALL
Trimethyl orthoformate (TMOF)	MC	0.75		0.250	3,564,061	PCPSG
With nitromethane		0.75			3,564,061	PCPSG
TMOF	MC	0.5			3,564,061	PCPSG
With acetonitrile		0.5		0.070	3,564,061	PCPSG
TMOF	MC	1.0			3,564,061	PCPSG
With trioxane		1.0			3,564,061	PCPSG
TMOF	MC	0.75			3,564,061	PCPSG
With 1,4-dioxane		0.75		0.180[c]	3,564,061	PCPSG
TMOF	MC	0.50			3,564,061	PCPSG
With acetonitrile		0.25		0.070	3,564,061	PCPSG
And *tert*-butyl alcohol		0.25		0.300	3,564,061	PCPSG
TMOF	MC	2.10			3,564,061	PCPSG
With methanol		0.60		0.260	3,564,061	PCPSG
And methylformate		0.30		0.250	3,564,061	PCPSG
Benzotriazole	PERC	0.5	0.1 to 2.5		3,337,471	DOW
Oxazole	MC	2	1 to 4		3,676,355	UKF
Polyamines (ethylenediamine, triethylenediamine, 4,4'-ethylenedimorpholine, pyrrole, 1,1'-ethylenedipiperidine, diisopropylamine, diethylenetriamine, tetraethylenepentamine, n-methylpyrrole	PERC, TCENE, CH	0.004	0.001 to 0.02		3,424,805	WCGG
N,N-Dimethyl-*p*-phenylenediamine	MC	0.13			3,546,125	DOW
N,N,N',N'-Tetramethyl-*o*-phenylenediamine	MC	1.1			3,546,125	DOW
N,N,N',N-Tetramethylbenzidine	MC	0.22			3,546,125	DOW

See footnotes at end of table, page 102.

(continued)

TABLE D-1 (continued)

Stabilizing compound	Solvent[a]	Typical solute concentration, wt %	Range of concentration, wt %	TLV, g/m^3	U.S. Patent number	Patent[b] issued to
Quaternary ammonium compounds	MC, TCENE, CH		0.005 to 0.2		3,314,892	CI
With volatile epoxy compounds			0.01 to 1.0		3,314,892	CI
And organic amines (pyridine, picoline, triethylamine, aniline, dimethylaniline, nalkylmorpholines, diisopropylamine, N-methylpyrrole)			0.005 to 0.2		3,314,892	CI
2-Methyl-2-oxazoline	MC	0.44			3,494,968	DOW
2-Phenyl-2-oxazoline	MC	0.65			3,494,968	DOW
2-(1-Aziridinyl)-2-oxazoline	MC	0.25			3,494,968	DOW
Diaziridine compounds and N-ethylpyrrole (1,2-diethyldiaziridine, N-methylpyrrole)	TCENE, CH	6.8			3,551,505	SCB
α-Methyl-1-aziridineethanol	MC		1.0 to 4.0		3,328,474	DOW
2-(1-Aziridinyl)ethyl acetate						
Lactams (Caprolactam)	MC, CH	0.5	0.05 to 5		3,496,241	FMC
With glycidol(2,3-epoxy-1-propanol)		0.25			3,496,241	FMC
(2,3, and 4)-Pyridinecarboxaldehyde	MC	0.25			3,444,248	DOW
(2,3, and 4)-Acetylpyridine	MC	0.50	0.36 to 0.54		3,444,248	DOW
(2,3, and 4)-Cyanopyridine	MC	0.35	0.31 to 0.39		3,452,108	DOW
p-Nitrobenzonitrile	MC	0.33			3,454,659	DOW
o-Nitrobenzonitrile (2-nitro-*p*-tolunitrile, 4-nitro-*m*-tolunitrile, 2,3-dimethyl-4-nitrobenzonitrile)	MC	0.77			3,454,659	DOW
(3 and 8)-Aminoquinoline	MC	0.32			3,472,903	DOW
Acetaldehyde dimethylhydrazone	TCENE, CH	0.025			3,417,152	MES
With butylene oxide		0.2			3,417,152	MES
With butylene oxide		0.1			3,417,152	MES
And propylene oxide		0.1		0.240	3,417,152	MES
And thymol (or formaldehyde dimethylhydrazone)		0.05			3,417,152	MES
Crotonaldehyde dimethylhydrazone	TCENE	0.025			3,403,190	MES
With butylene oxide		0.2			3,403,190	MES
And nitromethane		0.05		0.240	3,403,190	MES
With *p*-*tert*-pentylphenol		0.002			3,403,190	MES
p-(Dimethylamino)benzaldehyde	MC		0.11 to 11.1		3,444,247	DOW
Methoxyacetonitrile	MC	2.9			3,565,811	DOW
And butylene oxide		0.32			3,565,811	DOW
And nitromethane		0.44			3,565,811	DOW
Or propargyl alcohol		0.35		0.002[c]	3,565,811	DOW
Acetonitrile	MC	1.0		0.070	3,590,088	DNAG
And *tert*-butyl alcohol		5.0		0.300	3,445,532	DNAG
And 1,4-dioxane		0.7		0.180[c]	3,445,532	DNAG
Acetonitrile	MC	3.0		0.070	3,445,532	DNAG
And nitromethane		1.0		0.250	3,445,532	DNAC
And 1,4-dioxane		0.8		0.180[c]	3,445,532	DNAG
Acetonitrile	MC	0.5		0.070	3,445,532	DNAG
And *tert*-butyl alcohol		3.0		0.300	3,445,532	DNAG
And nitromethane		0.7		0.250	3,445,532	DNAG
Nitromethane	MC	3.0		0.250	3,549,715	PPG
With butylene oxide		1.0			3,549,715	PPG
With 2-propanol		3.0		0.980	3,549,715	PPG
3-Methoxy-1,2-epoxypropane	MC	0.5			3,536,766	DOW
With 1,4-dioxane		2.5		0.180[c]	3,536,766	DOW
And nitromethane		0.5		0.250	3,536,766	DOW
And methyl glycidyl ether		0.5			3,536,766	DOW
Propylene oxide	CFA	0.5	0.5 to 3.0		3,445,527	DKKK
With nitromethane		0.05		0.250	3,445,527	DKKK
3-Methoxyoxetane	MC	3.0			3,532,761	PPG
1,2-Dimethoxyethylene	MC	2.0	1 to 5		3,549,547	DOW

(continued)

See footnotes at end of table, page 102.

TABLE D-1 (continued)

Stabilizing compound	Solvent[a]	Typical solute concentration, wt %	Range of concentration, wt %	TLV, g/m³	U.S. Patent number	Patent[b] issued to
2-Methoxy-2,3-dihydropyran	MC	1.4			3,661,788	ICI
Or 2-ethoxy-2,3,-dihydropyran		0.5	0.5 to 2		3,661,788	ICI
And isopropyl nitrate		2			3,661,788	ICI
4,7-Dihydro-1,3-dioxepin	MC	4	2 to 10		3,518,202	DOW
And nitromethane		1	0.25 to 2	0.250	3,518,202	DOW
Or propargyl alcohol		0.5	0.25 to 0.5	0.002[c]	3,518,202	DOW
And butylene oxide		0.5	0.25 to 1.0		3,518,202	DOW
Or epichlorhydrin		0.5	0.25 to 1.0	0.019[c]	3,518,202	DOW
Furfuryl alcohol	MC	0.066		0.020	3,475,503	DOW
Furfuryl mercaptan	MC	0.11			3,475,503	DOW
5-Formylfurfuryl alcohol	MC	0.19			3,475,503	DOW
2-Thiophenmethanol	MC	0.47			3,475,503	DOW
2,5-Tetrahydrofurandimethanol	MC	0.29			3,475,503	DOW
2-(2 and 3)-Pyridyl ethanol	MC	0.32	0.28 to 0.35		3,475,503	DOW
o-Aminobenzyl alcohol	MC	0.37			3,475,503	DOW
p-Methoxybenzyl alcohol	MC	0.21			3,475,503	DOW
3-Methyl-2-thiophenemethanol	MC	0.33			3,475,503	DOW
1,3-Dioxolane	MC		1 to 3		Reissue 26,025	AR
With phenolic antioxidants (*p*-*tert*-butylphenol, 2,6-di-*tert*-butyl-*p*-cresol, nonylphenol, 4,4'-thiobis(6-*tert*-butyl)*m*-cresol)			0.01 to 0.1			
1,4-Dioxane	MC	2.84		0.180[c]	3,629,128	ETH
With nitromethane		0.3921		0.250	3,629,128	ETH
With butylene oxide		0.2601			3,629,128	ETH
With N-methylpyrrole		0.005			3,629,128	ETH
With diisopropylamine		0.003			3,629,128	ETH
3-Methylpropionaldehyde	MC	2			3,505,415	DNAG
4-Methyl-2-butanone	MC	2			3,505,415	DNAG
Isobutyric acid, methyl ester	MC	1			3,505,415	DNAG
And nitromethane		1		0.250	3,505,415	DNAG
4-Methyl-4-methoxy-2-pentanone	MC	1			3,505,415	DNAG
With acetonitrile		0.5		0.070	3,505,415	DNAG
And *tert*-butyl alcohol		0.5		0.300	3,505,415	DNAG
With *tert*-butyl alcohol		1		0.300	3,505,415	DNAG
And methyl ethyl ketone		1		0.590	3,505,415	DNAG
1,4-Cyclohexanedione	MC	0.25			3,546,305	DOW
1,2-Cyclohexanedione	MC	0.33			3,546,305	DOW
2,5-Butanedione	MC	0.17			3,546,305	DOW
2,5-Butanedione	MC	0.28			3,546,305	DOW
p-Benzoquinone	MC	0.24		0.0004	3,546,305	DOW
2,3-Dihydro-1,4-dithiin (also 5-methyl-2,3-dihydro-1,4-dithiin)	MC, TCENE		0.2 to 4.5		3,439,051	ICI
Polysulfones	PERC	0.092			3,396,115	DOW
Trimethylene sulfide	MC	0.17			3,467,722	DOW
3-Hydroxytrimethylene sulfide	MC	0.20			3,467,722	DOW
Isopropyl nitrate	MC	2	2 to 4		3,609,091	ICI
With acetonitrile		2			3,609,091	ICI
And nitromethane		1	0.75 to 1		3,609,091	ICI
And butylene oxide		0.25	0.1 to 1		3,609,091	ICI
With acrylonitrile		2	0.5 to 4		3,609,091	ICI
Any butylene oxide		0.25	0.1 to 1	0.045[c]	3,609,091	ICI
Iron benzoate	TCENE, PERC	12	10.2 to 14.3		3,527,703	DOW
Sodium benzoate	TCENE, PERC	0.025	0.020 to 0.027		3,527,703	DOW
Zinc benzoate	TCENE, PERC	10	0.41 to 38.3		3,527,703	DOW

See footnotes at end of table, page 102.

(continued)

TABLE D-1 (continued)

Stabilizing compound	Solvent[a]	Typical solute concentration, wt %	Range of concentration, wt %	TLV, g/m³	U.S. Patent number	Patent[b] issued to
Sodium didecyl phosphate (or sodium dioctyl phosphate)	PERC	1.5			3,441,620	STA
Benzyl fluoride	MC	0.14	0.82 to 8.2		3,681,469	DOW
Benzotrifluoride	MC	4.9			3,681,469	DOW
Ethyl propargyl ether	PERC	0.25			British 773,447	DIA
Propargyl benzoate	PERC	0.25			773,447	DIA
2-Butyne-1,4-diol-dibenzoate	PERC	0.25			773,447	DIA
With isoeugenol		0.01			773,447	DIA
Propargyl alcohol	AERO	0.01		0.002[c]	2,892,725	
Nitromethane	AER	2	0.1 to 5		3,085,116	DUP
Nitroethane	AER	1	0.1 to 5		3,085,116	DUP
2-Nitropropane	AER	2	0.1 to 5		3,085,116	DUP
Propargyl alcohol	TCENE	0.1	0.05 to 0.5	0.002[c]	2,803,676	DOW
With pyrrole		0.05	0.01 to 0.05		2,803,676	DOW
And diisopropylamine		0.001	0.0005 to 0.01		2,803,676	DOW
Methylbutynol (and 2 prior)	TCENE	0.1	0.05 to 0.5		2,803,676	DOW
1,4-Dioxane	CH	1			2,923,747	DOW
Nitromethane		1			2,923,747	DOW
Vinylidene chloride		0.5			2,923,747	DOW
2-Butyn-1,4-diol	AERO, CH	0.5			2,892,725	CEL
3-Methyl-1-butyn-3-ol	CH		0.1 to 0.5		2,542,551	RH
3-Methyl-1-butyn-3-ol (with thymol, di-*tert*-butyl-*p*-cresol, epichlorohydrin, butylene oxide, amines, dioxane)	CH		0.005 to 0.3		2,911,449	AIR

Note.—Blanks indicate no data.

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[a] MC -- Methyl chloroform; 1,1,1-trichlorethane
PERC -- Perchloroethylene
TCENE -- Trichloroethylene
AER -- Aerosols; trichlorofluoromethane and ethanol
CFA -- Chloro-fluoro alkanes
CH -- Chlorinated hydrocarbons
AERO -- Methylene chloride and methanol (aerosols)

[b] DOW -- Dow Chemical Corporation
PPG -- PPG Industries, Inc.
WCGG -- Wacker-Chemie GMBH, Germany
ALL -- Allied Chemical Corporation
PCPSG -- Produits Chimiques Peciney-Saint-Gobain, France
UKF -- Ugine Kuhlmann, France
CI -- Canadian Industries, Limited, Canada
SCB -- Solvay ANC Cie, Belgium
FMC -- FMC Corporation
MES -- Montecatini Edison Spa, Italy
DNAG -- Dynamit Nobel AG, Germany
DKKK -- Daikin Kogyo K. K., Japan
ICI -- Imperial Chemical Industries, Limited, Great Britain
AR -- Argus Chemical Corporation
ETH -- Ethyl Corporation
STA -- Stauffer Chemical Corporation
DIA -- Diamond Alkali Company
DUP -- E. I. Du Pont de Nemours and Company
CEL -- Celanese Corporation
RH -- Rohm & Haas Co.
AIR -- Air Reduction Corporation

[c] TLV for skin contact.

APPENDIX E

NEDS EMISSION DATA

Units in Appendix E are nonmetric to conform with their appearance in the original reference.

TABLE E-1. SUMMARY OF EMISSIONS DATA CONTAINED IN NATIONAL EMISSIONS DATA SYSTEM FOR STODDARD SOLVENT

State	Frequency of operation, % of yr	Stack height, ft	Emission rate, tons/yr	Type of calculation
Colorado	100	160	2	Guess.
Connecticut	67	21	281	NADB-approved non-EPA emission factor.
Kansas	33	10		Not applicable.
Maine		0		Not applicable.
Maine		0	1	Not applicable.
Michigan	67	0	137	Material balance.
Michigan	67	100	144	Not applicable.
Michigan	67	0	66	Emissions factor [AP-42(98) or pending].
Mississippi	33	20		Not applicable.
Nebraska	33	20	8	Guess.
New Hampshire	33	10	4	Material balance.
New Hampshire	100	40	75	Material balance.
North Carolina	67	30	10	Guess.
Ohio	33		15	Emission factor [AP-42(98) or pending].
Oklahoma	33	0	21	Emission factor [AP-42(98) or pending].
Vermont	67	0	18	Guess.
Washington	100	30	168	Material balance.
West Virginia	33	10	28	Guess.

Note.—Blanks indicate data not available.

TABLE E-2. SUMMARY OF EMISSIONS DATA CONTAINED IN NATIONAL EMISSIONS DATA SYSTEM FOR METHYLENE CHLORIDE

State	Frequency of operation, % of yr	Stack height, ft	Emission rate, tons/yr	Type of calculation
California	33		32	Guess.
Massachusetts	100	20	6	Material balance.
Vermont	67		39	Emission test measurement.
Vermont	100		23	Material balance.
Washington	100	30	1	Material balance.

Note.—Blanks indicate data not available.

TABLE E-3. SUMMARY OF EMISSIONS DATA CONTAINED IN NATIONAL EMISSION DATA SYSTEM FOR PERCHLOROETHYLENE

State	Frequency of operation, % of yr	Stack height, ft	Emission rate, tons/yr	Type of calculation
California	67		250	Not applicable.
California	67		190	Not applicable.
California	67		60	Not applicable.
California	67		16	Not applicable.
California	67	58	270	NADB-approved non-EPA emission factor.
California	100	0	91	Emission factor [AP-42 (98) or pending].
Indiana	67	62	201	Emission test measurement.
Indiana	100	30	336	Material balance.
Indiana	67	25	236	Material balance.
Maine	100	0	8	Not applicable.
Maine	100	0	9	Emission factor [AP-42 (98) or pending].
Massachusetts		90	4	Material balance.
Massachusetts	33	20	6	Material balance.
Massachusetts	67	20	5	Material balance.
Massachusetts	100	20	11	Material balance.
New Hampshire	67	10	35	Material balance.
Vermont	100		7	Guess.
Washington	100	30	6	Material balance.
Washington	100	35	8	Material balance.
Washington	33	25	7	Emission factor [AP-42 (98) or pending].

Note.—Blanks indicate data not available.

TABLE E-4. SUMMARY OF EMISSIONS DATA CONTAINED IN NATIONAL EMISSION DATA SYSTEM FOR TRICHLOROETHYLENE

State	Frequency of operation, % of yr	Stack height, ft	Emission rate, tons/yr	Type of calculation
California	33		246	Emission factor [AP-42 (98) or pending].
California	33		125	Guess.
California	100	0	8	NADB-approved non-EPA emission factor.
Colorado	100	160	113	Guess.
Colorado	33	140	20	Guess.
Kansas			74	Emission test measurement.
Kansas		90	309	Material balance.
Kansas	67	30	8	Material balance.
Kansas	100	20	13	Material balance.
Massachusetts	67	20	95	Material balance.
Massachusetts	100	0	2	Material balance.
Massachusetts	100	20	107	Material balance.
Massachusetts		20	1	Material balance.
Massachusetts	67	20	2	Material balance.
Massachusetts	100	20	13	Material balance.
Massachusetts	33	20	62	Material balance.
Washington	100	30	218	Material balance.
Washington	100	20	69	Material balance.
Washington	100	35	422	Material balance.
Washington	100	35	3	Material balance.
Washington	100	30	27	Material balance.
Washington	33	0	17	Material balance.
Washington	33	25	33	Emission factor [AP-42 (98) or pending].
Washington	67	30	116	Material balance.

Note.—Blanks indicate data not available.

TABLE E-5. SUMMARY OF EMISSIONS DATA CONTAINED IN NATIONAL EMISSIONS DATA SYSTEM FOR TRICHLOROETHANE

State	Frequency of operation, % of yr	Stack height, ft	Emission rate, tons/yr	Type of calculation
Arizona	100	10	308	Material balance.
Arizona	100	10	209	Material balance.
Arizona	100	20	14	Material balance.
California			4	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			17	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			87	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			8	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			44	NADB-approved non-EPA emission factor.
California			55	NADB-approved non-EPA emission factor.
California			10	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			11	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			28	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			10	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			8	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			14	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			21	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			8	NADB-approved non-EPA emission factor.
California			13	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			8	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			10	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			23	NADB-approved non-EPA emission factor.
California			31	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			17	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			297	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			23	NADB-approved non-EPA emission factor.

(continued)

TABLE E-5 (continued)

State	Frequency of operation, % of yr	Stack height, ft	Emission rate, tons/yr	Type of calculation
California			2	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			31	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			60	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			11	NADB-approved non-EPA emission factor.
California			11	NADB-approved non-EPA emission factor.
California			181	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			37	NADB-approved non-EPA emission factor.
California			14	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			8	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			24	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			10	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			36	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			27	NADB-approved non-EPA emission factor.
California			57	NADB-approved non-EPA emission factor.
California			133	NADB-approved non-EPA emission factor.
California			8	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			10	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			11	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			14	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			14	NADB-approved non-EPA emission factor.
California			11	NADB-approved non-EPA emission factor.
California			138	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.

(continued)

TABLE E-5 (continued)

State	Frequency of operation, % of yr	Stack height, ft	Emission rate, tons/yr	Type of calculation
California			18	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			12	NADB-approved non-EPA emission factor.
California			16	NADB-approved non-EPA emission factor.
California			22	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			45	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			18	NADB-approved non-EPA emission factor.
California			21	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			27	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			11	NADB-approved non-EPA emission factor.
California			18	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			21	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			10	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			21	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			19	NADB-approved non-EPA emission factor.
California	33		170	Emission factor (AP-42 or pending).
Indiana	67	30	32	Emission test measurement.
Indiana	33	28	38	Material balance.
Indiana	33	28	38	Material balance.
Indiana	33	28	38	Material balance.
Indiana	33	28	38	Material balance.
Indiana	100	30	61	Material balance.
Indiana	67	26	13	Emission factor (AP-42 or pending).
Indiana		50	585	Emission factor (AP-42 or pending).
Indiana	100	20	149	Material balance.
Indiana	67	20	43	Material balance.
Indiana	67	35	323	Material balance.
Indiana	100	25	11	Material balance.
Indiana	100	20	57	Material balance.
Indiana	67	30	21	Emission test measurement.
Indiana	100	25	28	Material balance.
Indiana	33	23	60	Material balance.
Indiana	100	46	55	Material balance.
Indiana	33	30	36	Material balance.
Indiana	67	25	133	Material balance.
Indiana	100	10	48	Material balance.
Iowa	100	44	0	Not applicable.
Iowa	33	35	0	Not applicable.
Maine	100	20	45	Emission factor (AP-42 or pending).
Maine	100	0	3	Not applicable.
Maine	100	0	24	Emission factor (AP-42 or pending).
Massachusetts	67	20	10	Material balance.
Massachusetts	67	20	141	Material balance.
Massachusetts	100	20	153	Material balance.
Massachusetts	67	20	26	Material balance.
Michigan				Not applicable.
New Hampshire	100	10	51	Guess.
North Carolina	33	20	53	Material balance.
North Carolina	33	30	7	Not applicable.
North Carolina	67	40	16	NADB-approved non-EPA emission factor.
Vermont		0	16	Material balance.
Vermont	100		16	Material balance.
Vermont	100	0	65	Material balance.

Note.—Blanks indicate data not available.

TABLE E-6. SUMMARY OF EMISSIONS DATA CONTAINED IN NATIONAL EMISSIONS DATA SYSTEM FOR OTHER/NONCLASSIFIED SOLVENTS

State	Frequency of operation, % of yr	Stack height, ft	Emission rate, tons/yr	Type of calculation
Arizona	67	35	373	Material balance.
Arizona	100	35	2,540	Material balance.
California			4	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			13	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			11	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			12	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			59	NADB-approved non-EPA emission factor.
California			25	NADB-approved non-EPA emission factor.
California			22	NADB-approved non-EPA emission factor.
California			17	NADB-approved non-EPA emission factor.
California			131	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			31	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			13	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			76	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			46	NADB-approved non-EPA emission factor.
California			12	NADB-approved non-EPA emission factor.
California			17	NADB-approved non-EPA emission factor.
California			11	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			23	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			17	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			8	NADB-approved non-EPA emission factor.
California			64	NADB-approved non-EPA emission factor.
California			25	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			21	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			19	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			81	NADB-approved non-EPA emission factor.
California			37	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			11	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			32	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			61	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			13	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			10	NADB-approved non-EPA emission factor.

(continued)

TABLE E-6 (continued)

State	Frequency of operation, % of yr	Stack height, ft	Emission rate, tons/yr	Type of calculation
California			9	NADB-approved non-EPA emission factor.
California			29	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			552	NADB-approved non-EPA emission factor.
California			37	NADB-approved non-EPA emission factor.
California			36	NADB-approved non-EPA emission factor.
California			28	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			43	NADB-approved non-EPA emission factor.
California			417	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			63	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			16	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			13	NADB-approved non-EPA emission factor.
California			17	NADB-approved non-EPA emission factor.
California			29	NADB-approved non-EPA emission factor.
California			242	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			27	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			13	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			19	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			34	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			118	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			16	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			40	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			31	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			72	NADB-approved non-EPA emission factor.
California			10	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			15	NADB-approved non-EPA emission factor.
California			64	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			16	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			8	NADB-approved non-EPA emission factor.
California			21	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			71	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			17	NADB-approved non-EPA emission factor.
California			26	NADB-approved non-EPA emission factor.

(continued)

TABLE E-6 (continued)

State	Frequency of operation, % of yr	Stack height, ft	Emission rate, tons/yr	Type of calculation
California			2	NADB-approved non-EPA emission factor.
California			10	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			67	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			17	NADB-approved non-EPA emission factor.
California			8	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			20	NADB-approved non-EPA emission factor.
California			8	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			8	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			8	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			11	NADB-approved non-EPA emission factor.
California			23	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			14	NADB-approved non-EPA emission factor.
California			16	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			38	NADB-approved non-EPA emission factor.
California			39	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			103	NADB-approved non-EPA emission factor.
California			7	NADB-approved non-EPA emission factor.
California			73	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			20	NADB-approved non-EPA emission factor.
California			61	NADB-approved non-EPA emission factor.
California			28	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			85	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			39	NADB-approved non-EPA emission factor.
California			124	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			34	NADB-approved non-EPA emission factor.
California			233	NADB-approved non-EPA emission factor.
California			131	NADB-approved non-EPA emission factor.
California			10	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			19	NADB-approved non-EPA emission factor.
California			11	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			33	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			56	NADB-approved non-EPA emission factor.
California			6	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			30	NADB-approved non-EPA emission factor.
California			11	NADB-approved non-EPA emission factor.
California			177	NADB-approved non-EPA emission factor.

(continued)

TABLE E-6 (continued)

State	Frequency of operation, % of yr	Stack height, ft	Emission rate, tons/yr	Type of calculation
California			10	NADB-approved non-EPA emission factor.
California			10	NADB-approved non-EPA emission factor.
California			42	NADB-approved non-EPA emission factor.
California			4	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			10	NADB-approved non-EPA emission factor.
California			2	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			1	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			13	NADB-approved non-EPA emission factor.
California			12	NADB-approved non-EPA emission factor.
California			12	NADB-approved non-EPA emission factor.
California			9	NADB-approved non-EPA emission factor.
California			56	NADB-approved non-EPA emission factor.
California			26	NADB-approved non-EPA emission factor.
California			99	NADB-approved non-EPA emission factor.
California			96	NADB-approved non-EPA emission factor.
California			15	NADB-approved non-EPA emission factor.
California			77	NADB-approved non-EPA emission factor.
California			20	NADB-approved non-EPA emission factor.
California			205	NADB-approved non-EPA emission factor.
California			3	NADB-approved non-EPA emission factor.
California			5	NADB-approved non-EPA emission factor.
California			21	NADB-approved non-EPA emission factor.
California			75	NADB-approved non-EPA emission factor.
California	33	0	49	Material balance.
California	33	0	72	Material balance.
California		0	42	Material balance.
California		0	30	Material balance.
California	67	0	60	Material balance.
California			43	Material balance.
California	67		154	Material balance.
California	67		400	Material balance.
California	100	0	1,370	Guess.
California			940	NADB-approved non-EPA emission factor.
California	33	0	8	NADB-approved non-EPA emission factor.
California		10		Not applicable.
California	67	5	2	Material balance.
Colorado		35	30	Material balance.
Illinois	67	30	13,100	Guess.
Illinois	100	50	350	Emission factor [AP-42 (98) or pending].
Illinois	100	28	9	Guess.
Illinois	100	24	112	Guess.
Illinois	67	20	88	Guess.
Illinois	33	22	263	Guess.
Illinois	33	25	16	Guess.
Illinois	67	23	48	Guess.
Illinois	33	20	679	Material balance.
Illinois	67	35	81	Emission factor [AP-42 (98) or pending].
Illinois	67	35	263	Guess.
Illinois		50	1	Guess.
Illinois	67			Not applicable.
Illinois		25	18	Guess.
Illinois	33	36	96	NADB-approved non-EPA emission factor.
Illinois	33	36	96	NADB-approved non-EPA emission factor.
Illinois	33	10	175	Guess.
Indiana	100	0	297	Guess.
Indiana	33	14	117	Material balance.
Indiana	67	10	302	Material balance.
Indiana	100	30	356	Material balance.
Indiana	33	10	48	Material balance.
Indiana	100	28	419	Material balance.
Indiana	67	0	168	Material balance.
Indiana	100	60	10	Material balance.

(continued)

TABLE E-6 (continued)

State	Frequency of operation, % of yr	Stack height, ft	Emission rate, tons/yr	Type of calculation
Indiana	67	25	82	Material balance.
Indiana	67	46	106	Material balance.
Indiana	67	32	60	Material balance.
Indiana	33	25	18	Material balance.
Iowa	67	12	0	Not applicable.
Iowa	33	33	0	Not applicable.
Iowa	33	24	0	Not applicable.
Iowa	33	6	0	Not applicable.
Iowa	33	27	0	Not applicable.
Kansas	100			Not applicable.
Kansas		10		Not applicable.
Kansas				
Kansas	67	0	125	Guess.
Kansas	67	0	4	Guess.
Kansas	100	0	31	Guess.
Kentucky	33	25	2	Material balance.
Kentucky	67	16	5	Emission test measurement.
Kentucky	67	2	18	Emission test measurement.
Kentucky	67	62	149	Material balance.
Kentucky	33	20	300	Emission factor [AP-42 (98) or pending].
Kentucky	67	30	245	Material balance.
Kentucky	33	10	17	NADB-approved non-EPA emission factor.
Kentucky	33	10	13	NADB-approved non-EPA emission factor.
Kentucky	100	30	66	Material balance.
Kentucky	33	30	19	Material balance.
Kentucky	67	26	13	Material balance.
Kentucky	67	20	18	Material balance.
Kentucky	67	37	1	Material balance.
Kentucky	67	64	0	Not applicable.
Maine	67	5	40	Not applicable.
Massachusetts	33	20	14	Material balance.
Massachusetts	100	20	4	Material balance.
Massachusetts	67	20	3	Material balance.
Massachusetts	33	20	193	Material balance.
Massachusetts	100	40	336	Guess.
Massachusetts	67	20	5	Material balance.
Massachusetts	33	20	11	Material balance.
Massachusetts	33	20	1	Material balance.
Massachusetts	67	20	20	Material balance.
Massachusetts	67	20	3	Material balance.
Massachusetts	33	20	21	Material balance.
Massachusetts	33	20	8	Material balance.
Massachusetts	33	20	7	Material balance.
Massachusetts	33	20	24	Material balance.
Massachusetts	67	0	17	Material balance.
Massachusetts	33	20	22	Material balance.
Massachusetts	33	20	21	Material balance.
Massachusetts	33	20	8	Material balance.
Massachusetts	33	15	15	Material balance.
Massachusetts	33	20	1	Material balance.
Massachusetts	67	20	10	Material balance.
Massachusetts	33	20	8	Material balance.
Massachusetts	33	20	6	Material balance.
Massachusetts	33	20	8	Material balance.
Massachusetts	33	20	5	Material balance.
Massachusetts	67	20	11	Material balance.
Massachusetts	67	20	8	Material balance.
Massachusetts	33	20	60	Material balance.
Massachusetts	100	20	27	Material balance.
Massachusetts	33	20	13	Material balance.
Massachusetts	67	20	6	Material balance.
Massachusetts	33	20	8	Material balance.
Massachusetts	33	20	77	Material balance.
Massachusetts	33	20	6	Material balance.
Massachusetts	33	20	5	Material balance.
Massachusetts	33	20	7	Material balance.

(continued)

TABLE E-6 (continued)

State	Frequency of operation, % of yr	Stack height, ft	Emission rate, tons/yr	Type of calculation
Massachusetts	33	20	5	Material balance.
Massachusetts	67	20	47	Material balance.
Massachusetts	67	20	36	Material balance.
Massachusetts	33	15	6	Material balance.
Massachusetts	33	20	10	Material balance.
Massachusetts	67	20	20	Material balance.
Massachusetts		20	18	Material balance.
Massachusetts	33	20	2	Material balance.
Massachusetts	33	20	4	Material balance.
Massachusetts	33	20	11	Material balance.
Massachusetts	67	20	25	Material balance.
Massachusetts	33	20	40	Material balance.
Massachusetts	33	20	5	Material balance.
Massachusetts	33	20	5	Material balance.
Massachusetts	33	20	20	Material balance.
Massachusetts	67	20	6	Material balance.
Massachusetts	33	20	7	Material balance.
Massachusetts	67	20	39	Material balance.
Massachusetts	67	15	6	Material balance.
Massachusetts	33	20	22	Material balance.
Massachusetts	33	20	116	Material balance.
Massachusetts	33	20	20	Material balance.
Massachusetts	33	20	27	Material balance.
Massachusetts	33	20	4	Material balance.
Massachusetts	67	22	41	Material balance.
Massachusetts	33	20	7	Material balance.
Massachusetts	33	20	15	Material balance.
Massachusetts	33	20	7	Material balance.
Massachusetts		20	11	Material balance.
Massachusetts	33	20	9	Material balance.
Massachusetts	33	20	12	Material balance.
Michigan	67		180	Guess.
Michigan	100	0	390	Not applicable.
Michigan	67	0	530	Emission factor [AP-42 (98) or pending].
Michigan				Not applicable.
Michigan	33		616	Guess.
Mississippi	33	0	1	Guess.
Mississippi				Not applicable.
Mississippi	100		123	Material balance.
Mississippi	100	30	10	Material balance.
Mississippi	33	30		Not applicable.
Mississippi	67	8	66	Guess.
Mississippi	67	20		Not applicable.
Nebraska	33	20	12	Guess.
New Hampshire	33	10	52	Material balance.
New Hampshire	67	16	78	Material balance.
New Hampshire	100	10	4	Guess.
New Hampshire	100	10	79	Guess.
New Hampshire	67	10	114	Material balance.
New Hampshire	33	10	21	Material balance.
New Hampshire	33	10	16	Material balance.
New Hampshire	100	10	49	Material balance.
New Hampshire	33	10	1	Material balance.
New Jersey	100	45	21	Emission test measurement.
New Jersey	100	41	7	Not applicable.
New York	33	40	5	Material balance.
North Carolina	67	50	14,600	Emission test measurement.
North Carolina	67	40	13	Guess.
North Carolina	67	25	30	Material balance.
North Carolina	100	35	42	NADB-approved non-EPA emission factor.
North Carolina	100	30	161	Guess.
North Carolina	67	30	25	NADB-approved non-EPA emission factor.
North Carolina	33	0	2	Emission factor [AP-42 (98) or pending].
North Carolina	67	0	104	Emission factor [AP-42 (98) or pending].
North Carolina	67	20	3	NADB-approved non-EPA emission factor.
North Carolina	100	30	8	NADB-approved non-EPA emission factor.

(continued)

TABLE E-6 (continued)

State	Frequency of operation, % of yr	Stack height, ft	Emission rate, tons/yr	Type of calculation
North Carolina	67	20	12	Not applicable.
North Carolina	33	20	6	Not applicable.
North Carolina	67	40	29	Material balance.
North Carolina	67	40	15	Material balance.
North Carolina	67	40	93	Guess.
Ohio	67	0	2,700	Material balance.
Ohio	67		966	Guess.
Ohio	100	103	21,000	Not applicable.
Ohio	67	50	402	Material balance.
Ohio	100	148	1,160	Guess.
Ohio	33	4	99	Guess.
Ohio	67		387	Guess.
Ohio	67	24	149	NADB-approved non-EPA emission factor.
Ohio	33	7	19	Material balance.
Oklahoma	33	43	24	Emission test measurement.
Oklahoma	67	29	7	Emission test measurement.
Oklahoma	67	29	4	Emission test measurement.
Oklahoma	67	38	5	Emission test measurement.
Oklahoma	33	43	7	Emission test measurement.
Oklahoma	67	29	34	Emission test measurement.
Oklahoma	33	42	21	Emission test measurement.
Oklahoma	67	42	31	Emission test measurement.
Pennsylvania	100	36	50	Material balance.
Pennsylvania	33	123	12	Material balance.
Pennsylvania	33	88	34	Material balance.
Pennsylvania	100	0	78	Material balance.
Pennsylvania	33	0	13	Material balance.
Pennsylvania	33	36	26	Emission factor [AP-42 (98) or pending].
Pennsylvania	33	25	10	Material balance.
Pennsylvania	33	33	17	Material balance.
Pennsylvania	33	0	3	Emission factor [AP-42 (98) or pending].
Pennsylvania	33	0	7	Emission factor [AP-42 (98) or pending].
Pennsylvania	67	0	9	Material balance.
Pennsylvania	33	20	8	Material balance.
Pennsylvania	33	35	5	Material balance.
Pennsylvania	33	0	3	Emission factor [AP-42 (98) or pending].
Pennsylvania	33	10	49	Material balance.
Pennsylvania	33	30	1	Emission factor [AP-42 (98) or pending].
Pennsylvania	33	0	3	Emission factor [AP-42 (98) or pending].
Pennsylvania	33	0	2	Material balance.
Pennsylvania	33	35	5	Emission factor [AP-42 (98) or pending].
Pennsylvania	33	22	13	Emission factor [AP-42 (98) or pending].
Pennsylvania	33	0	3	Material balance.
South Carolina	100	6	120	Material balance.
South Carolina	67	15	7	Emission factor [AP-42 (98) or pending].
South Carolina	100	25	180	Material balance.
South Carolina	100	30	82	Material balance.
South Carolina	33	30	36	Material balance.
Tennessee	33	9	8	Material balance.
Tennessee	33	9		Not applicable.
Tennessee	33	10	10	Material balance.
Vermont	67		115	Not applicable.
Virginia	33		218	Emission factor [AP-42 (98) or pending].
Washington	100	30	137	Material balance.
Washington	67	20	45	Material balance.
Washington	100	20	108	Material balance.
Washington	100	20	85	Emission factor [AP-42 (98) or pending].
Washington	100	35	120	Material balance.
Washington	100	35	4	Material balance.
Washington	100	30	3	Material balance.
Washington	67	30	95	Material balance.
Wisconsin	33	25	167	NADB-approved non-EPA emission factor.
Wisconsin	33	28	9	NADB-approved non-EPA emission factor.
Wisconsin	33	45	0	Not applicable.
Wisconsin	33	26	79	NADB-approved non-EPA emission factor.
Wisconsin	33	55	32	

Note.—Blanks indicate data not available.

APPENDIX F

SAMPLE CALCULATIONS FOR GEOGRAPHICAL DISTRIBUTION OF COLD CLEANERS

To determine the geographical distribution of cold cleaners, the distribution of cold cleaning plants was first determined by SIC. As an example, the state of Tennessee will be used.

For SIC 22, Reference 1 lists 172 textile plants for the state of Tennessee; for SIC 25, Reference 2 lists 288 furniture and fixture plants; for SIC 33, Reference 3 lists 100 primary metal plants; for SIC 34, Reference 4 lists 416 fabricated metal plants; for SIC 35, Reference 5 lists 473 nonelectrical machinery plants; for SIC 36, Reference 6 lists 181 electrical equipment plants; for SIC 37, Reference 7 lists 159 transportation equipment plants; for SIC 38, Reference 8 lists 46 instrument plants; and for SIC 39, Reference 9 lists 299 miscellaneous manufacturing plants. Thus for SIC 22 through SIC 39, the total number of plants utilizing industrial degreasing is 2,064.

For auto repair shops, Reference 10 lists 127,203 shops in the United States. No distribution by state is provided. To determine the number of auto repair shops in Tennessee, the number of shops in the United States was assumed to be distributed by population. Using 1970 census figures, Tennessee was found to have 2.07% of the total U.S. population. Applying this figure to the total number of repair shops, Tennessee is estimated to have 2,634 auto repair shops.

From Reference 11, the total number of automotive dealers and gas stations in the United States are found to be 121,369 and 226,455, respectively. Again no geographical distribution is available. As before, assuming both auto dealers and gas stations to be distributed in the United States by population, the number of auto dealers and gas stations in Tennessee are estimated to be 2,514 and 4,690, respectively.

For maintenance shops, Reference 1 lists a total of 320,701 manufacturing plants in the United States. The assumption is made that all maintenance shops, as classified here, exist in manufacturing plants. The geographical distribution lists 5,647 manufacturing plants in Tennessee.

Thus total plants in Tennessee for all categories are 17,549.

From Reference 14, the total number of cold cleaning operations in the United States is estimated to be 1,220,555. The total number of U.S. degreasing plants is estimated (using the described process for all states) to be 931,513. Dividing the number of operations by the number of plants results in an average of 1.31 degreasers per plant for all plants, regardless of type. Applying 1.31 to 17,549 plants results in the estimate of 22,989 cold cleaning operations in the state of Tennessee.

GLOSSARY

affected population: Number of persons around a typical plant that is utilizing a degreasing operation who are exposed to a source severity greater than 0.1 or 1.0, as specified.

cold cleaning: Removal of undesirable matter from various metals or glass with an organic solvent in a liquid rather than a vapor state.

desiccant: Drying agent.

dragout: In metal degreasing, the solvent entrained with or contained on the piece of work as it leaves the degreaser.

fabric scouring: Removal of undesirable matter from a textile fiber with an organic solvent in a liquid state before subsequent fabrication into a saleable product such as carpet, or yarns.

freeboard chiller: Second set of condenser coils located slightly above the primary condenser coils of a vapor degreaser. The chiller impedes diffusion of solvent vapors from the vapor zone into the work atmosphere.

emission factor: Quantity of a species that is emitted per unit weight of solvent consumed.

kauri-butanol value: Volume in milliliters at 25°C of the solvent required to produce a defined degree of turbidity when added to 20 g of a standard solution of kauri resin in normal butyl alcohol.

kier: Large vat or boiler used in bleaching.

mineral spirit: Clear, water-white refined hydrocarbon solvent and divalent petroleum distillate with a minimum flash point of 21°C.

naphthas: Petroleum distillates used as solvents or fuels containing hydrocarbon chains beginning with pentanes. This may include small concentrations of heptane, hexane, benzene, xylene, toluene, kerosene, and heavy aromatics. In this report, the term includes both high-flash and low-flash naphthas.

solvent degreasing: Physical method of removing grease, wax, soil, or other undesirable matter from various metal, glass, plastic, or textile items with an organic solvent.

source severity: Ratio of the ground level concentration of each emission species to its corresponding ambient air quality standard (for criteria pollutants) or to a reduced TLV (for noncriteria emission species).

stabilizer: Any compound when added to another compound decreases its ability to decompose.